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An Analysis Methodology

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This study addresses the problem of analyzing nonpoint source pollution impacts from agriculture. A methodology for regional-level planning is presented that, with further refinement, could prove of significant value for broad analyses of large numbers of policy alternatives, including best management practices. The analytical method developed allows the simultaneous examination of the water quality impacts of selected agricultural practices and the economic effects that alternative practices and nonpoint source pollution control policies have on the farmer. The nonpoint source pollution control problems that the methodology addresses are limited to those that are amenable to solution by incremental on-farm adjustments for damage reduction. The proposed methodology includes a farm model, a water quality model, and a qualitative approach for the assessment of the social and economic impacts of water quality changes on downstream users. It may be applied to evaluate government nonpoint source pollution control policies and the effects of alternative agricultural futures. The methodology's use for these purposes is evaluated through an illustrative example based on data from the Black Creek watershed in Northeastern Indiana and a synthesized downstream impoundment.

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An Analysis Methodology

by

Meta Systems, Inc.
Cambridge, Massachusetts 02138

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Project Officer

Thomas E. Waddell
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30605

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30605

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools to help pollution control officials achieve water quality goals through watershed management.

Agricultural sources contribute significantly to water pollution problems in many areas of the United States, but control efforts to reach water quality goals must recognize the social and economic dimensions of alternative approaches. This report presents a technique for analyzing the water quality and economic impacts of alternative activities and nonpoint source pollution control policies as a means of identifying best management practices. The methodology should aid the environmental decisionmaker in establishing balanced nonpoint source pollution control policies.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

This study addresses the problem of analyzing nonpoint source pollution impacts from agriculture. It was undertaken to determine the feasibility of developing an analytical method that can be applied to the assessment of controls for reducing nonpoint source pollution from agriculture. The analytical method developed allows the simultaneous examination of 1) the water quality impacts of selected agricultural practices and 2) the economic effects that alternative practices and nonpoint source pollution control policies have on the farmer. The nonpoint source pollution control problems that the methodology addresses are limited to those that are amenable to solution by incremental on-farm adjustments for damage reduction.

The proposed methodology includes 1) a farm model, which accepts as exogenous inputs alternative agricultural practices available to the farmer and determines the net revenues resulting from each alternative; 2) a water quality model, which analyzes the water quality impacts of the selected agricultural practices and which is composed of (a) a watershed model that describes the pollutants generated by the farming practices and their impact on river water quality and which evaluates soil loss, and (b) an impoundment model which evaluates the impoundment water quality effects of the watershed pollutants; and 3) a qualitative approach for the assessment of the socioeconomic impacts of water quality changes on downstream users. The methodology is designed to facilitate the comparison of alternative agricultural practices for the purpose of identifying best management practices (BMP's). It also may be applied to evaluate government nonpoint source pollution control policies and the effects of alternative agricultural futures. The methodology's use for these purposes is evaluated through an illustrative example based on data from the Black Creek watershed in Northeastern Indiana and a synthesized downstream impoundment.

It appears that the development of such a methodology for regional-level planning is feasible and would be of significant value for broad analyses of large numbers of policy alternatives, including identification of BMP's. However, the methodology is currently at a preliminary stage of development, and further refinements are necessary to make it fully operational.

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SECTION 1

INTRODUCTION

This study addresses the problem of analyzing nonpoint source pollution impacts from agriculture. It was undertaken to determine the feasibility of developing an analytical method that can be applied to the assessment of controls for reducing nonpoint source pollution from agriculture. It is widely recognized that the goals of the Water Pollution Control Act Amendments of 1972 will be achieved only if in addition to point source pollution, nonpoint source pollution is controlled. Authority exists under PL 92-500 and PL-217 for EPA, in conjunction with individual states to devise policies and initiate control programs to manage nonpoint source pollution. However, progress has been slow. Many reasons can be cited, including strong economic forces that are in conflict with attempts at environmental control, and the lack of detailed knowledge of physical, chemical, and biological processes associated with environmental impact of pollutants from nonpoint sources. Such knowledge is needed to identify pertinent and defensible policies for analyzing the impacts of agricultural practices.

Agri-environmental problems can be classified in various ways. For this study we have devised the following classification.

A. Problems in which human or ecosystem health is at issue:

   1. those involving residuals generation and transport with a large array of chemical transformations over a wide temporal scope and near-linear damage functions, such as synthetic biocides and toxics;

   2. those involving residuals generation and transport of a few defined elements and non-linear (or threshold) damage functions, such as nitrates.

B. Problems in which major concern is with aesthetics, recreation, or other economic impacts:

   1. those involving generation and transport of residuals, such as sediment and nutrients;

   2. those involving long-term land productivity, such as soil loss;

   3. those involving spatial diversity, such as monoculture.

In solving environmental problems, at least two different approaches are emerging. One involves incremental adjustments at local or regional levels, while the other is directed to controls at the national level after the examination of large-scale trade-offs.

It is believed that the environmental problems of types A-2, B-1, B-2, and B-3 are amenable to solution by incremental approaches based on on-farm adjustments to reduce damages. In this study we are concerned with the development of a methodology focused on water pollution problems of types A-2 and B-1.

Environmental problems of type A-1 are not amenable to an incremental-policy-change approach (i.e., on-farm adjustment). Reasons include:

1) Many synthetic organic chemicals behave largely in an unknown fashion in nature; their persistence and transport through food chains and degradation patterns are often not well understood.
2) The risks involved with biocides and toxics may be large and are uncertain; they involve generations to come as well as all persons now living. Unintended consequences impact other crops, fields, times, and populations.
3) The variety of chemicals makes screening of each for safety difficult. To prove a chemical safe oftens requires years of testing.
4) Damage is apparently at least linearly related to dose.

Taking these characteristics of biocides and toxics into consideration, it can be argued that the best approach to their control is one which examines the broad questions of use, quantity used, exposure, potential adverse collateral consequences, etc., over time and asks if the risks are worth the economic costs of doing without.

Methods of evaluating the environmental and socio-economic impacts of agricultural practices should exhibit the following characteristics.

1) Compatibility between data availabilities and requirements
2) Robustness against a wide range of alternative agricultural futures
3) Capability of evaluating major policy options
4) Ease of understanding and communications
5) Usefulness at the appropriate planning level
6) Applicability to the full range of on-farm adaptive options.

Based on these characteristics, the focus of this study is on farm decision-making (where crop and technology are decided) and on aggregation of the individual decisions to a regional level, rather than on modeled regional level decision-making where these decisions are not made (but often wished).

METHODOLOGY DEVELOPMENT

Figure 1 is a flow chart of the proposed methodology and provides a framework for identifying the analytic techniques employed and the data inputs required. It shows 1) the farm model, which accepts alternative agricultural practices available to the farmer as exogenous inputs and determines the net revenues resulting from each alternative; 2) the water quality model, which analyzes the water quality impacts of the selected agricultural practices and which is composed of (a) a watershed model that describes the pollutants generated by the farming practices and their impact on river water quality and evaluates soil loss, and (b) an impoundment model that evaluates the impoundment water quality effects of the watershed pollutants; and 3) a qualitative approach for the assessment of the socio-economic impacts of water quality changes on downstream users. Each of these is described in more detail below and in the following sections. As Figure 1 indicates, the methodology is designed to facilitate the comparison of alternative agricultural practices for the purpose of identyfing and evaluating best management practices (BMP's).

Figure 1a shows how the methodology may be applied to evaluate government nonpoint source pollution control policies and the effects of alternative agricultural futures. The control policies and alternative futures are inputs to the methodology. Examples illustrating the use of the methodology for these purposes will be discussed below.

Use of the Illustrative Example

After completing the literature review for this study, it appeared to us that the most effective way to approach the determination of the feasibility of developing a methodology would be to work through an illustrative example. The example would allow an assessment of the logic and completeness of the methodology as well as of the requirements for applying the methodology in a planning context. In order to minimize required field work and maximize data available for the example presented in this report, we sought a well-studied, agricultural watershed with a downstream impoundment. The latter was considered necessary for an adequate example of an assessment of water quality impacts in both flowing and impounded waters. We were unable to find a locality meeting all these requirements; therefore, to implement the illustrative example, we used the Black Creek watershed in northeastern Indiana (a U.S. EPA, USDA demonstration project) and synthesized a downstream impoundment with characteristics typical of those found in the Corn Belt. Data from impoundments in this region were obtained from the EPA's National Eutrophication Survey and other sources that permitted regional calibration of the impoundment water quality models. The work done on the Black Creek watershed (see Black Creek Study, Final Report, October 1977) provided a good source for some of the economic, soils, and water quality data needed for calibration and illustrative application of the methodology.

Agricultural Future Scenarios

The evaluation of environmental control policies for the future requires analysis against a predicted structure of agriculture. The farmer's decisions

FIGURE 1: METHODOLOGY FOR ASSESSMENT OF WATER QUALITY IMPACTS AND SOCIO-ECONOMIC IMPACTS OF AGRICULTURAL PRACTICES

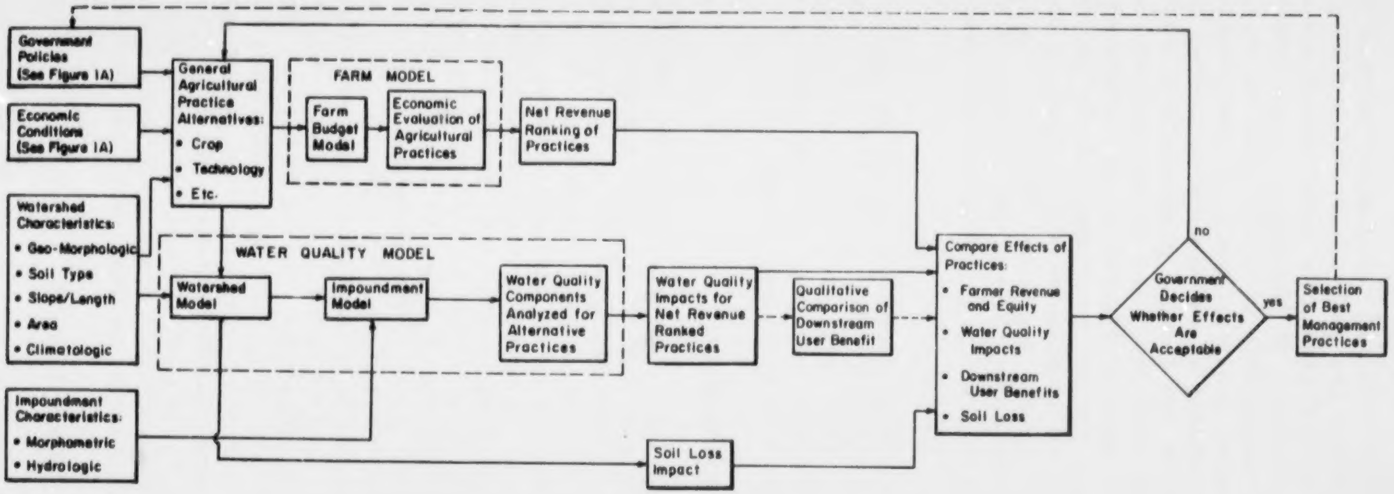
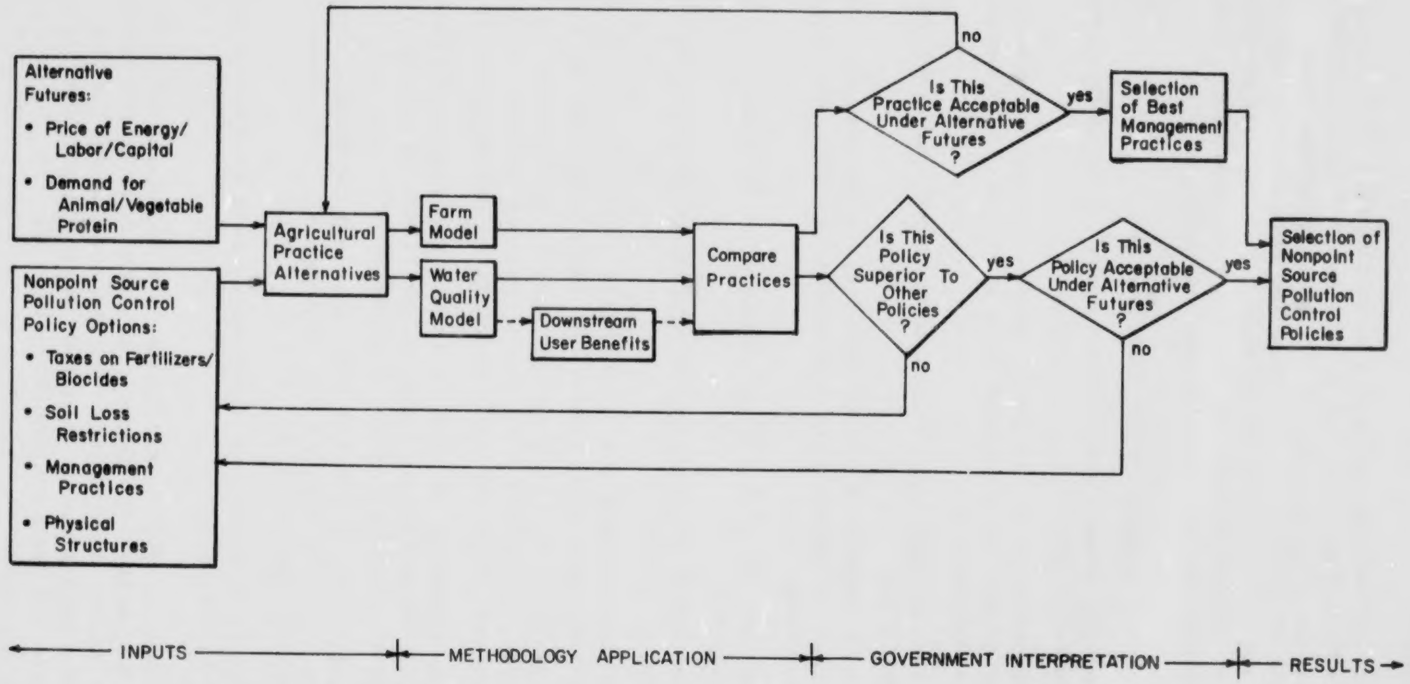

Government Policies (See Figure 1A)
Economic Conditions (See Figure 1A)
Watershed Characteristics:
• Geo-Morphologic
• Soil Type
• Slope/Length
• Area
• Climatologic
Impoundment Characteristics:
• Morphometric
• Hydrologic
General Agricultural Practice Alternatives:
• Crop
• Technology
• Etc.
FARM MODEL
Farm Budget Model
Economic Evaluation of Agricultural Practices
Net Revenue Ranking of Practices
WATER QUALITY MODEL
Watershed Model
Impoundment Model
Water Quality Components Analyzed for Alternative Practices
Water Quality Impacts for Net Revenue Ranked Practices
Qualitative Comparison of Downstream User Benefit
Soil Loss Impact
Compare Effects of Practices:
• Farmer Revenue and Equity
• Water Quality Impacts
• Downstream User Benefits
• Soil Loss
Government Decides Whether Effects Are Acceptable
no
yes
Selection of Best Management Practices

FIGURE 1A: USE OF METHODOLOGY FOR ASSESSMENT OF NONPOINT SOURCE POLLUTION CONTROL OPTIONS UNDER ALTERNATIVE FUTURES


Alternative Futures:
• Price of Energy/ Labor/Capital
• Demand for Animal/Vegetable Protein
Nonpoint Source Pollution Control Policy Options:
• Taxes on Fertilizers/ Biocides
• Soil Loss Restrictions
• Management Practices
• Physical Structures
Agricultural Practice Alternatives
Farm Model
Water Quality Model
Downstream User Benefits
Compare Practices
Is This Practice Acceptable Under Alternative Futures ?
no
yes
Selection of Best Management Practices
Is This Policy Superior To Other Policies ?
yes
no
Is This Policy Acceptable Under Alternative Futures ?
yes
no
Selection of Nonpoint Source Pollution Control Policies
INPUTS
METHODOLOGY APPLICATION
GOVERNMENT INTERPRETATION
RESULTS

must be analyzed against assumptions regarding the forces driving the agricultural system.

Without attempting to give a complete list of current trends in modern U.S. agriculture that have led to the current level of water pollution from agriculture, we present some of the more important ones. Because these forces are affected by government policies and because they affect nonpoint source pollution, it is important to include consideration of such trends in a quantitative framework such as the one proposed here. Some of these broad national trends can be characterized as follows:

1) tendency toward larger farm units;
2) tendency toward absentee ownership (including corporate ownership and land speculation);
3) reduction of direct labor inputs because of rising wages, the growth in organized farm labor, and farm capital intensification;
4) large capital investments in machinery manufactured by a few firms;
5) a high degree of market uncertainty because of international market integration, in addition to weather and other natural phenomena;
6) emphasis on high yield, single crop farming (intensive monoculture);
7) increasing utilization of synthetic chemical and nonrenewable energy use;
8) tendency toward non-integration of livestock rearing activities, with feed production separated from feedlots;
9) difficulty of new farmer access to farming and of old farmer adjustments to new conditions because of large capital stock represented by land, animals, and machinery;
10) concentration of crop marketing and crop distribution activities in fewer and larger firms, including vertical integration from farm to retail store;
11) large federal subsidies to agriculture through irrigation, power, flood control, price supports, and research/development extension; and
12) emphasis on product appearance, ease of mechanical handling, and storability.

Although most of these trends have led to environmental impairment, this is not to argue that the destructive environmental consequences of U.S. farming result solely from them. The destruction of the fragile topsoil of northern New England more than 150 years ago and the great dust bowls of this century have had long lasting effects. Nor can one conclude from these trends that their attendant social costs necessarily outweigh the benefits associated with increased food production. The point here is that many national policies and future economic factors influence the range of agricultural practices that will be considered by farmers and hence influence nonpoint source pollution from agriculture. Because of time and resources, we have done little on this aspect of methodology development, and this represents a serious limitation of this study. However, because of the uncertainties in the future of agriculture and in order for the methodology to be flexible and operational, it will be necessary in subsequent work to evaluate agricultural practices across a broad range of alternative futures. One such future is continuation of the above trends towards a highly concentrated food/fiber production system. Some believe that such a future, if achieved, would be unstable. In Section 6 we discuss briefly other possible future settings derived from past modifications and extrapolation of current trends and forces that would influence the environmental impacts from agriculture.

Agricultural Practices and Farm Budgets

As the first step in this feasibility study, a farm budget is developed that assumes the current agricultural structure. A set of agricultural practices representative of the options available to a farmer in a particular watershed is selected. In the example presented in this report, 11 practices (plus two modifications) are selected, and farm budgets are developed for a uniform farm of 250 acres on each of the three predominant soils in the Black Creek watershed. Timing of operations and agricultural practices such as livestock integration and organic farming that are important for both farm revenues and environmental impacts were not considered because of a lack of available data and the limited scope of this study.

Water Quality Impacts of Agricultural Practices

To judge the water quality effects of the agricultural practices, the water quality impacts of each practice/soil combination are analyzed as the second step in this example. Watershed and water quality analysis is based on the assumption of homogeneity of the watershed reflected in the farm level analysis. This is, of course, illustrative at this preliminary state of methodology development. Later use of this method would involve evaluation of the aggregate economic and environmental impacts in a heterogenous watershed. Thus in assessing agricultural practices, a watershed is assumed to be comprised of a number of fields of equal characteristics. This provides a rough measure of the unit emissions and water quality impacts -- impacts of a given field/soil type/agricultural practice combination as desired in the assessment of the impact of agricultural practices. A more realistic evaluation of these practices on a heterogenous watershed (soils, slopes, farm sizes, and other characteristics) is the next step in the development of a usuable methodology now that this example of how to proceed with the analysis of the economic and environmental impacts of various agricultural practices on a homogeneous watershed has proven feasible.

This evaluation is designed for assessments of long-term average watershed responses and water quality impacts. In this analysis the following water quality parameters are considered.

1) impoundment sedimentation (kg/m^2-yr),
   a measure of the amount of sediment deposited on the bottom of the impoundment per year and thus of the impoundment's useful lifetime;

2) impoundment sediment outflow concentration (kg/m^3),
   a measure of the amount of sediment suspended in waters withdrawn from the impoundment;

3) river and impoundment nitrogen concentrations (g/m^3),
   an indication of nitrate levels in the waters;

4) river light extinction coefficient (m^{-1}),
   a measure of the resistance to light penetration in the river due to turbidity and color;

5) impoundment light extinction coefficient (m^{-1}),
   a measure of the resistance to light penetration in the surface waters of the impoundment due to turbidity, color, and algal growth;

6) impoundment biomass (g chl-a/m^3),
   a measure of the concentration of suspended algae in the surface waters of the impoundment during the summers and thus a measure of the degree of eutrophication.

For each practice, the watershed models predict average loadings of sediment (sand, silt, and clay fractions), nitrogen, phosphorus, and color as functions of field/soil characteristics. Transport of water quality components from the watershed is represented in two phases (dissolved and sediment-bound) and in two streams (surface runoff and sub-surface drainage). The water quality models estimate the impact of these loadings on the average concentrations of the respective components in the downstream river and impoundments. Impoundment water quality response is also assessed with regard to mean summer transparency and chlorophyll-a concentration, which are important indices of eutrophication. While water quality impacts are traditionally assessed with regard to effects of organic loadings (DOD) on dissolved oxygen levels, such effects are usually critical for discharges of unstable organic matter under low-flow conditions. The impacts considered in the framework for analysis developed for this study are more relevant to evaluating the water quality effects of erosion control practices than are traditional BOD/DO impacts.

Impact Assessment and Policy Evaluation

The third step involves a comparison of the net revenue of each of the farm practices with the water quality impacts of each practice. Policies that would induce those practices that are environmentally advantageous can then be examined. Policies considered include:

1) conservation practice subsidies or requirements;

2) prohibition of certain cultivation practices;

3) gross soil loss restrictions;

4) gross soil loss taxes;

5) fertilizer limitations or taxes; and

6) manure/legume subsidies or restrictions.

Government policies that are not instituted specifically for environmental management purposes -- for example, price supports -- are regarded as subsumed under definitions of alternative agricultural futures.

Socio-Economic Impacts of Non-Farm Users

Finally, a qualitative description of the impacts of different practices on downstream users is made indicating the direction of the water quality change in terms of a particular water use and the conflicts among different users.

SECTION 2

CONCLUSIONS

Conclusions are presented under three headings: 1) methodology; 2) implementation of a methodology; and 3) data requirements.

METHODOLOGY

1. The following classification appears useful in considering agro-environmental problems:

   A. Problems where human or ecosystem health is at issue:

      1) those involving residuals generation and transport with an extraordinary array of chemical transformations over a wide temporal scope and near-linear damage functions, such as synthetic biocides and toxics;

      2) those involving residuals generation and transport of a few defined elements and non-linear (or threshold) damage functions; such as nitrates.

   B. Problems where major concern is with aesthetics, recreation, or other economic impacts:

      1) those involving residuals generation and transport, such as sediment and nutrients;

      2) those involving long-term land productivity, such as soil loss;

      3) those involving spatial diversity, such as monoculture.

Environmental problems of types A-2, B-1, B-2, and B-3 are amenable to solution by incremental approaches based on on-farm adjustments to reduce damages. This study addresses the feasibility of developing methodology focused on water pollution problems of types A-2 and B-1.

Environmental problems of type A-1 are not amenable to an incremental policy change approach (i.e., on-farm adjustment), the reasons being:

- Many synthetic organic chemicals behave largely in an unknown fashion in nature; their persistence, transport through food chains, and degradation patterns are often not well-understood.
- The risks involved with biocides and toxics may be large and are uncertain; they involve generations to come as well as all persons now living. Impacts are on other crops, fields, times, and people than intended.
- The variety of chemicals makes screening of each for safety difficult. To prove a chemical safe may require years of testing.

- Damage is apparently linearly related to dose.

As a result of these characteristics of biocides and toxics, it can be argued that the best approach to their control is one that examines the national scene and asks if the risks are worth the economic costs of doing without. Analysis of long-lived residuals might be feasible if data to make the necessary transformations were ever to become available.

2. Methods to evaluate the environmental and socio-economic impacts of agricultural practices should exhibit the following characteristics.

- Compatibility between data availabilities and requirements.
- Robustness against a wide range of alternative agricultural futures and agricultural practices.
- Capability of evaluating major policy options.
- Ease of understanding and communicating.
- Usefulness at the state level.
- Applicability to the full range of on-farm adaptive options.

3. To develop a useable method for policy analysis by those responsible for evaluation and implementation of BMP's, it is necessary to focus on farm decision making (where crops and technology are decided) and on aggregation of the individual decisions to a regional level, rather than on modeled regional-level decision making where decisions on practices and crops are not made. A farm budget approach is thus the appropriate first step in a methodology.

4. A broad range of agricultural practices must be evaluated, including livestock integration, in order to obtain a full understanding of the range of environmental impacts and control alternatives.

5. Water quality impacts of different farm practices on different soil types for sediment, nitrogen, phosphorus, and color can be compared using the methodology suggested in this report. It is shown that comparison of practices based on water quality components in some, but not all, cases leads to results that are in the same direction (but not of the same magnitude) as comparisons based solely upon gross soil erosion estimates. Erosion control and water quality improvement strategies are not always similar. In those cases where the water quality component of greatest importance and gross soil erosion changes are in the same direction, using soil loss as a proxy measurement for water quality can facilitate the initial evaluation of BMP's.

6. The advantages of using long-term-average time scales for the watershed and water body response models include:

- simplified analysis;
- reasonable data requirements facilitating use of national, regional, and local monitoring and experimental data for model calibration and application;
- a methodology based in part on existing, well-tested, and widely applied models (e.g., the Universal Soil Loss Equation);

- flexibility and ease of implementation;
- response models that are easily understood by decision makers;
- response models that are appropriate for assessment of such long-term water quality problems as sedimentation and eutrophication.

Nevertheless, use of long-term-average time scales precludes direct assessments of:

- watershed and water body responses under extreme meteorologic conditions;
- effects of the timing of various agricultural operations (such as incremental application of fertilizer);
- seasonal variations in water quality induced by normal seasonal variations in watershed loadings, which may be particularly important in rivers and impoundments with relatively short hydraulic residence times;
- analysis of the transport and fate of relatively short-lived compounds.

Modification of the methodology to permit assessments of average seasonal responses would be feasible without losing many of the above-listed advantages of a long-term-average approach. This is because the USLE and the SCS curve number models, which form partial bases for the assessment, can be applied to predict seasonal responses.

7. It appears feasible to develop an analytical framework for the evaluation of alternative agricultural practices in terms of farm economics and water quality impacts. The example provided in this report illustrates an evaluation of a homogeneous watershed. This study does not include a general application of mixed farm operations on heterogeneous watersheds. It has not proven feasible to integrate estimation of the socio-economic impacts of downstream water quality changes (i.e., externalities) into the framework. A qualitative presentation of the downstream impacts is possible. This presentation provides some insight into the possible upstream-downstream conflicts.

8. The literature does not include any examples of theoretically valid benefit estimation methodologies that are directly applicable to the agricultural non-point source pollution problem. A number of studies discussed in the report provide examples of a benefit evaluation that could be applied. But such a study would require extensive collection of primary data and would therefore be expensive to implement.

9. At present the method does not take into account planting time, the timing of fertilizer and biocide applications, or harvesting time, all of which are important in that they affect both farm revenues and the water quality impacts of different practices.

10. The methodology can be used to evaluate agricultural practices against some of the future conditions (e.g., higher energy prices) that might prevail. It is important to evaluate alternative practices and policies in light of alternative future scenarios that are depicted as market product price changes, unit production factors, or other changes.

IMPLEMENTATION/COMPUTATION

1. The farm budget analysis needs to be automated. This would allow inclusion of more farm practices in the evaluation and testing for sensitivity to the timing of farming activities.

2. An LP model would be useful in asssisting in the evaluation of policies, once the watershed and water quality models have been refined.

3. The computations involved in performing the water quality analysis are relatively simple and straightforward. They can be easily performed with the aid of a hand calculator or an inexpensive computer program. Sensitivity and error analyses are facilitated by the latter.

INPUT DATA REQUIREMENTS

1. The relatively simple methodology developed to assess water quality impacts has been shown to allow use of national, regional, and local data sources for calibration purposes. Most of the parameter estimates describing fundamental processes in the watershed and water body would be expected to be valid at least on a regional basis. The types of localized (e.g., field or soil-specific) data required to implement the model are frequently available.

2. A preliminary survey of data availability and the results of sensitivity analyses indicate that improved estimates of the relative impacts of these agricultural practices could be obtained through more accurate specifications of the parameter estimates and/or functional forms used to represent the following relationships or processes in the watershed/water body response models:

   a. sediment delivery, as related to drainage basin characteristics and sediment texture.

   b. sediment texture, as related to soil texture and erosion rate;

   c. phosphorus trapping in impoundments, as related to sedimentation and hydrologic/morphometric characteristics;

   d. the origins and dynamics of dissolved color in watersheds and water bodies;

   e. the leaching of dissolved phosphorus from surface crop residues during snowmelt (this is particularly important for assessments of reduced tillage alternatives);

   f. seasonal variations in suspended solids and color concentrations in impoundments;

   g. turbidity and light extinction in rivers and impoundments, as related to suspended solids, color, and algal concentrations;

   h. enrichment of surface soils in phosphorus and organic matter as a function of tillage practice;

i. denitrification in soils, as related to net or total nitrogen input rates and soil characteristics.

Some of the needs may be satisfied by a more exhaustive search of the literature and other data sources; others may require initiation of additional monitoring and/or experimental work.

3. Data for the farm budget are largely available for conventional farm practices, but must be collected on a watershed by watershed basis· some of the data, such as yield response to fertilizer and biocide application and equipment costs for varying farm sizes, are difficult to obtain and/or derive. Data for a broader set of agricultural practices that include differing farm and equipment sizes and livestock integration that can have significant impacts on water quality are difficult to obtain.

4. Data for benefit evaluation are scarce (or do not exist), preventing reliable estimation of a relationship between water quality parameters and value measurements.

5. More data and analysis are required to provide a basis for interpreting the chlorophyll-a predictions with regard to the possible harmful effects of increased eutrophication versus the possible beneficial effects of increased fish production. Development and integration of a model for predicting impoundment dissolved oxygen levels as a function of external and internal sources of oxygen demand would be helpful.

SECTION 3

RECOMMENDATIONS

1. Expand the number of agricultural practices evaluated to include, for example, variations in fertilizer applications, timing of farming activities, and livestock integration, and develop a classification scheme for the aggregation of farms within a watershed. These improvements would describe the watershed in more operational (i.e., realistic) terms and therefore provide greater utility for evaluating alternative BMPs.

2. Expand the types of policies considered and evaluate the sensitivity of farm net incomes to policy factors such as the amount of tax or level of subsidy.

3. Expand the number and types of alternative future scenarios considered to include:

   a. market product price changes;

   b. labor/energy cost changes; and

   c. product demand shifts.

4. The water quality assessment should include:

   a. Modification of the water quality models to permit the assessment of seasonal-average watershed and water body responses with regard to all quality components; transport and fate of relatively stable, toxic compounds, including heavy metals and biocide residues; dissolved oxygen responses in stratified impoundments; and various instream alternatives for controlling the impacts of agriculture on water quality, including, among other things, sedimentation basins, artificial mixing, and reservoir operating policies.

   b. Additional sensitivity and error analyses to identify critical data needs within the water quality model framework.

   c. A comprehensive search for additional data to satisfy these needs and to identify processes requiring additional monitoring and/or experimental investigation.

   d. Empirical research to further develop data collection methods for estimating one or more of the benefit categories, including human health, recreation, or aesthetics benefits as related to physical water quality measurements.

5. Investigate the application of methodologies (such as Paretian analysis) to a qualitative or non-monetary evaluation of the impacts of agricultural policies affecting water quality in the context of conflicts among interest groups.

SECTION 4

DEVELOPMENT OF A FARM MODEL

While major market and regulatory pressures -- such as prices, taxes, subsidies, government regulations -- are exerted at a regional or national level, it is the farmer who responds by choosing his crops and methods of farming. For this reason the methodology starts with a farm budget.

We assume the farmer desires to maximize net revenues from the agricultural use of his land subject to judgmental constraints that restrict his willingness to implement drastic changes that imply unusually high risks. The farm model does not, for example, depict net revenue if the farmer has income-producing ventures other than his agricultural operations or if, for example, he shifts from row and field crops to feed lot operations. The farmer chooses a set of agricultural practices that include:

1) crop rotation;
2) tillage practices;
3) structural erosion and drainage control practices;
4) levels of chemical application.

These choices are represented as inputs to the farm model for the calculation of a variety of costs associated with operating the farm in the specified manner. This required developing a data base for the model. The procedure set forth by Dr. Klaus Alt (See Appendix C, EPA, 1976) was used.[1] Each element of cost was updated for 1977 prices and modified where necessary to adapt the model for the Black Creek area.[2] The changes were based on published data for Black Creek and the State of Indiana, opinions of farm experts in the Black Creek area and at several universities, and information obtained from farm equipment dealers.

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[1] Several farm models are available (e.g., the Purdue Crop Budget). The Alt model was selected because it is likely that Appendix C will receive widespread use by agencies involved in the development of BMP's. Dr. Alt was most helpful in discussing the adjustment of his model.

[2] All estimates for the farm model as adapted to Black Creek and the sources of information used in that process are presented in Appendix A of this report (unattached, available from EPA). All details associated with the farm practices, such as types and quantities of fertilizers and biocides, size and usage of farm implements, including custom hiring and grain drying procedures, are also contained in Appendix A (Farm Model).

Additional inputs to the model specify expected yields and market prices for each crop. Net revenue is then calculated as follows:

$$\text{Net Revenue} = \sum_{c=1}^{c=n} Y_c P_c A_c - C$$

where Y_c = yield per acre of crop c

P_c = price per unit yield for crop c

A_c = number of acres producing crop c

n = number of crops grown in rotation

C = cost associated with specified farm practice

Table 1 identifies major categories of cost and revenue data incorporated in the model.

Eleven farm practices available to farmers in the case study area were selected. These are identified and described in Table 2. Two of the farm practices for growing corn, soybeans, wheat, and hay in rotation were expanded. This was done to include the option available to the farmer of custom hiring for planting wheat and meadow and harvesting hay. The custom hiring alternative was included because it seems unrealistic that a farmer adopting the farm crop rotation pattern would purchase all the specialized equipment needed for each crop.

Each practice was evaluated on three soil types characteristic of the Black Creek case study area. These are termed upland, ridge, and lowland soils. Different levels of chemical treatment and seeding are associated with each soil, and crop yields vary. The definitions of the farm practices and variations associated with soil type were developed by Meta Systems in consultation with farm experts involved in the Black Creek project at Purdue University.

Because of the limitation of long-term averages in the water quality analysis, considerations of timing of agricultural operations such as planting and harvesting were not included. While the farm budget model, as presented here, captures the major elements important for assessing the economic impacts of alternative nonpoint source pollution control policies on the farmer, further modifications would be necessary before it could be used effectively in a planning context. Most importantly, the model should be automated, perhaps employing a revenue-maximizing linear programming model for policy analysis. This would permit explicit consideration of the timing of farm operations and other factors, and sensitivity analyses would be easy to perform. Several automated models, such as the Purdue Crop Budget, are available and might be adapted to this use. Nevertheless, we caution that

TABLE 1: FARM MODEL: ELEMENTS OF COST AND REVENUE

Costs	Revenues
Terracing	Corn
-Construction	-Yield
-Maintenance	-Price
Machinery	Soybeans
-Fixed Cost	-Yield
-Maintenance	-Price
Tractor	Wheat
-Fixed Cost	-Yield
-Maintenance and Repair	-Price
Fuel	Hay
-Tractor	-Yield
-Combine	-Price
Seed	
-Corn	
-Soybeans	
-Wheat	
-Meadow	
Fertilizer	
-Nitrogen	
-Phosphorus	
-Potassium	
-Equipment Rental	
Biocides	
-Herbicides	
-Insecticides	
Labor	
-Direct Labor	
-Overhead	
Other Costs	
-Grain Drying	
-Interest on Operating Capital	

TABLE 2: MAJOR FEATURES OF A SELECTED SET OF FARM PRACTICES IN THE BLACK CREEK AREA

Crops	Tillage Practice	Soil Conservation Practice	Abbreviated Designation of Farm Practice
Continuous Corn (CC)	Conventional tillage, fall turn plow (CV)	without terracing	CC-CV
Continuous Corn (CC)	Conventional tillage, fall turn plow (CV)	with terracing	CC-CVT
Continuous Corn (CC)	Fall shred stalks, chisel plow, spring disk (CH)	without terracing	CC-CH
Continuous Corn (CC)	Fall shred stalks, chisel plow, spring disk (CH)	with terracing (T)	CC-CHT
Continuous Corn (CC)	Fall shred, no till planting (NT)	without terracing	CC-NT
Corn-Soybean Rotation (CB)	Conventional tillage, fall turn plow (CV)	without terracing	CB-CV
Corn-Soybean Rotation (CB)	Fall shred, chisel plow, spring disk (CH)	without terracing	CB-CH
Corn-Soybean Rotation (CB)	Fall shred, no-till planting (NT)	without terracing	CB-NT
Corn-Soybean Rotation (CB)	Fall shred, no-till planting (NT)	with terracing (T)	CB-NTT
Corn-Soybean-Wheat-Hay Rotation (CBWH)	Conventional tillage fall turn plow for corn; no-till planting for soybean, wheat, hay	without terracing	CBWH* CBWH
Corn-Soybean-Wheat-Hay Rotation (CBWH)	Fall shred stalks, no-till planting for all crops, increased use of herbicides (NT)	without terracing	CBWH*-NT CBWH-NT

Note: Entry in parentheses used where needed to distinguish specific component of farm practice.

*indicates farmer-owned equipment for wheat and meadow planting and for hay mowing, raking, and baling, rather than custom hiring for these operations.

near optimum solutions always be examined with respect to important factors that may not be incorporated in such a model.

In applying the farm model three fictitious 250-acre farms representative of conditions in the Black Creek area of Northeast Indiana are considered. One farm is on the uplands soil, one on ridge soil, and one on lowlands soil (the properties of these soils are described in Section 3). Table 3 shows the revenues and costs for each of these farms, assuming uniform adoption of one of the eleven farm practices in the Black Creek area and existing government policies in effect. Highest revenue is achieved with the corn, soybean cropping pattern and chisel plowing on all three farms. The revenue from the corn-soybean rotation with conventional tillage is, however, almost as high (within two percent). These and other results from the farm model are discussed in Section 6.

The purpose of constructing a farm model is to evaluate agricultural practices under consideration as Best Management Practices for the impacts on farm income, water pollution loading, and water quality. Together with the proposed government policies designed to encourage these practices, the farm and water quality models should be able to incorporate consideration of at least the following policies:

1) conservation practice subsidies or requirements;
2) prohibition of certain cultivation practices;
3) gross soil loss restriction;
4) gross soil loss taxes;
5) fertilizer limitations or taxes; and
6) manure/legume subsidies or restrictions.

Investigation of such policies is carried out by 1) modifying the appropriate cost or revenue factors in the farm model and recomputing the net revenues; 2) estimating changes in soil erosion and other water quality impacting parameters; and 3) jointly evaluating the impacts on farm revenues and water quality. The use of the farm model in this kind of evaluation is illustrated in Section 6.

In addition to evaluating government policies for pollution control, the farm model can be used to assess future conditions that may have an impact on the farmer. Alternative futures can be postulated for government policies that are not formulated specifically for purposes of environmental management, such as price subsidies. Alternative futures might depict changes in economic conditions, such as increasing prices for energy that affect prices of fuel used on the farm and purchased farm inputs of fertilizer and biocides. These changes could alter the farmer's choice of crops, tillage practice, chemical application and hence induce different impacts on water quality. An example of this application of the farm model is also presented in Section 6.

TABLE 3: SUMMARY OF FARM MODEL OUTPUT -- 1977 DOLLARS, IN THOUSANDS
(UNDER EXISTING GOVERNMENT POLICIES)

FARM PRACTICE / REVENUE AND COST	TILLAGE PRACTICES				ROTATIONS						TERRACES		
	CORN, CONVENTIONAL TILLAGE	CORN, CHISEL PLOW	CORN, NO-TILL	CORN, SOYBEAN, CONVENTIONAL TILLAGE	CORN SOYBEAN, CHISEL PLOW	CORN SOYBEAN, NO-TILL	CORN, SOYBEAN, WHEAT, HAY, PARTIAL USE OF HERBICIDES		CORN, SOY-BEAN, WHEAT HAY, NO-TILL		CORN, CONVENTIONAL TILLAGE	CORN, CHISEL PLOW	CORN, SOY-BEAN, NO-TILL
	(CC-CV)	(CC-CH)	(CC-NT)	(CB-CV)	(CB-CH)	(CB-NT)	(CBWH*)	(CBWH)	(CBWH*-NT)	(CBWH-NT)	(CC-CVT)	(CC-CHT)	(CB-NTT)
GROSS REVENUE													
A. UPLAND SOIL	52.5	52.5	49.9	46.3	46.3	44.4	43.0	43.0	43.0	43.0	56.0	56.0	47.4
B. RIDGE SOIL	65.0	65.0	65.0	59.1	59.1	57.9	51.8	51.8	51.8	51.8	68.5	68.5	60.9
C. LOWLAND SOIL	65.0	65.0	52.0	59.1	59.1	50.7	49.9	49.9	49.9	49.0	68.5	68.5	53.7
COSTS													
A. UPLAND SOIL	39.7	39.1	43.0	32.9	32.6	32.3	34.4	30.6	34.2	30.3	46.4	45.8	39.9
B. RIDGE SOIL	41.4	40.9	44.9	33.3	33.1	32.7	34.7	31.0	34.4	30.7	48.2	47.6	39.3
C. LOWLAND SOIL	42.7	42.1	45.5	34.8	34.5	34.1	35.4	31.7	35.1	31.4	49.4	48.9	40.7
NET RETURN													
A. UPLAND SOIL	12.8	13.4	6.9	13.5	13.7	12.2	8.5	12.4	8.8	12.8	9.6	10.2	8.6
B. RIDGE SOIL	23.6	24.1	20.1	25.8	26.1	25.1	17.4	20.8	17.4	21.1	20.3	20.9	21.5
C. LOWLAND SOIL	22.3	22.9	6.5	24.4	24.6	16.6	14.5	18.1	13.9	17.6	19.1	19.6	13.0

NOTE: COLUMNS MAY NOT ADD DUE TO ROUNDING.

*INDICATES CUSTOM HIRING.

SECTION 5

WATER QUALITY IMPACT ANALYSIS

INTRODUCTION

The next step in the methodology involves development and use of mathematical models to provide quantitative means of estimating the water quality impacts of agricultural practices. The development of these models is described in detail in unattached Appendices B, C, and D of this report. The models have been calibrated and applied to assess the changes in water quality resulting from implementation of 11 farm practices described in Section 4 on each of three field/soil types.

Figure 2 depicts the separation of the water quality analysis into two major sections:

1) the watershed, or runoff model, which is characterized as generating different loadings of pollutants depending on agricultural activities and watershed characteristics.
2) the impoundment, where water quality is dependent upon the type and quantity of loadings from the watershed and upon impoundment characteristics.

In this scheme the river is represented as a medium for transporting the pollutant loadings from the watershed to the impoundment. Water quality conditions in the river reflect these loadings, which enter the river in surface runoff and groundwater base flow and are transported in dissolved and sediment-bound phases. River water quality is estimated at the point of entry into the impoundment. Pollutant losses in overland flow and river transport are aggregated.

The water quality impact analysis includes the following components that may influence the suitability of waters for beneficial uses:

1) sediment (suspended solids, turbidity);
2) phosphorus;
3) nitrogen;
4) dissolved color;
5) transparency (as influenced by turbidity, color, and algal growth);
6) algal growth (as measured by chlorophyll-a concentration).

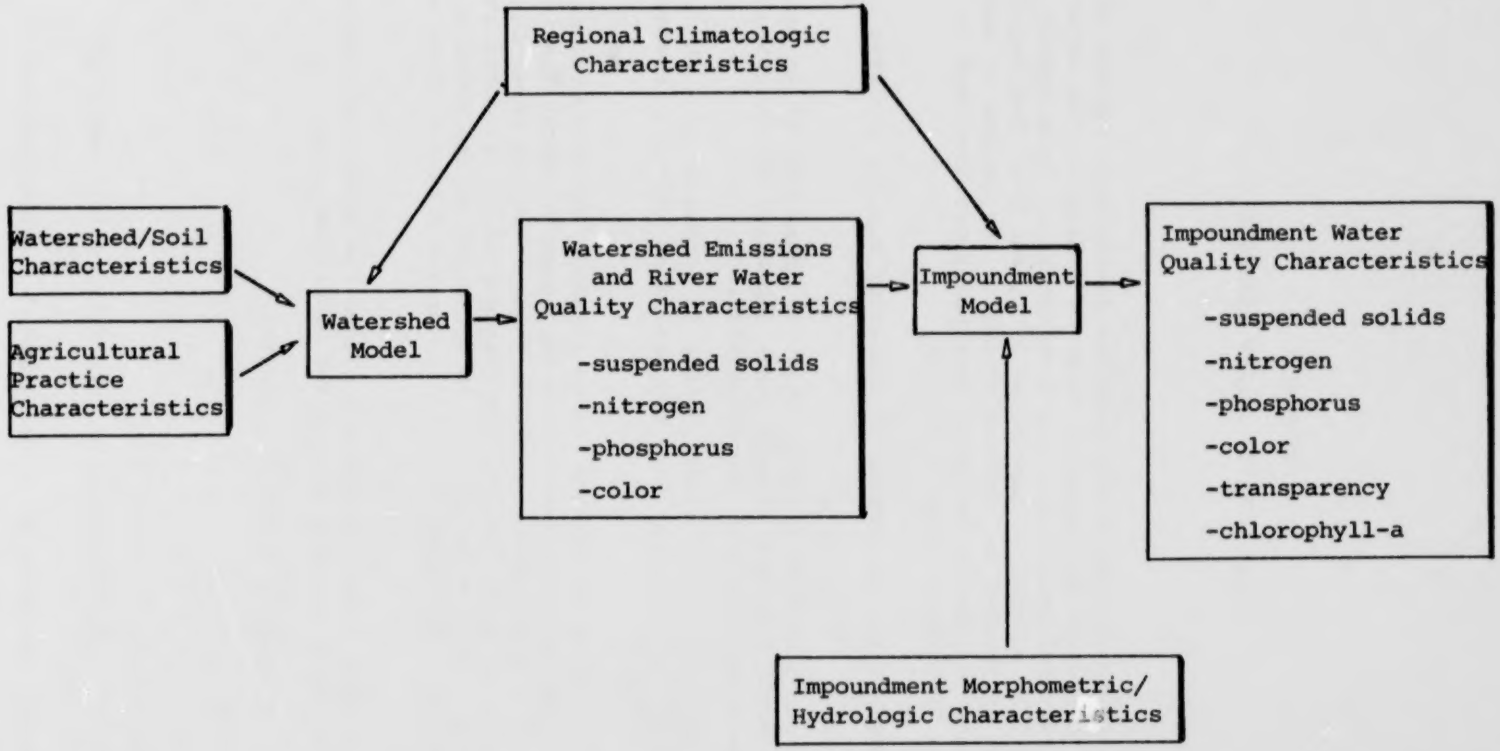
Regional Climatologic Characteristics
Watershed/Soil Characteristics
Agricultural Practice Characteristics
Watershed Model
Watershed Emissions and River Water Quality Characteristics
-suspended solids
-nitrogen
-phosphorus
-color
Impoundment Model
Impoundment Water Quality Characteristics
-suspended solids
-nitrogen
-phosphorus
-color
-transparency
-chlorophyll-a
Impoundment Morphometric/ Hydrologic Characteristics

FIGURE 2: SCHEMATIC VIEW OF THE WATERSHED/IMPOUNDMENT WATER QUALITY ANALYSIS

Dissolved oxygen, biocide residues, and biocides are additional water quality components relevant to the analysis of water quality impacts of agricultural practices that have not been included in the framework. The model framework could be adapted to consider dissolved oxygen in stratified impoundments as influenced by external and internal (photosynthetic) organic matter loadings. While it is not feasible at this time to model effectively the behavior of relatively short-lived biocides in the type of framework developed here, consideration of relatively stable biocides and biocide residues may be possible if and when basic data are available. This possible modification is left for future work.

The model framework described below should not be viewed as a static or final form, but as a preliminary and evolving one. Application of sensitivity and error analysis techniques to the framework will serve to guide future efforts at refining the methodology. Such efforts would include:

1) obtaining and analyzing additional data for parameter estimation;
2) modifying several functional forms;
3) including additional interactions or mechanisms;
4) considering different time scales for averaging; and
5) considering additional components.

It is apparent that a variety of approaches could be taken in modeling the behavior of the water quality components in watersheds, rivers, and impoundments. Prior to describing the specifics of our approach, it would be appropriate to discuss briefly the factors that were considered in selecting or formulating the models.

BASIS OF MODELING APPROACH

In selecting a modeling approach to the physical land-water interface, factors related to both defining the overall project goal and performing the particular analysis have to be considered. Without entering a lengthy discussion, we would like to briefly document our approach to the model selection process.

Two points that impact the selection of models are related to the projects's goals.

- Applying models in a policy-making context requires availability of flexible and operational models. Quick computation and recomputation of the impacts of alternative settings (i.e., scenario/policy/practice mix) can only be accomplished if a low-cost operational tool is available whose input requirements are limited.
- Given the goals of improving/developing a methodology for evaluating management practices in terms of water quality impact, it is necessary to include all the processes and parameters of the

land/water interface related to different farm practices and estimation of those water quality components relevant to existing and anticipated future standards or criteria.

The premise of our approach is that no single model can adequately capture the land/water interface (Meta Systems, 1976): aspects of the interface have to be modeled separately, and the models have to be linked up in a homologous way. Literature exists on problems encountered in developing models, linking models describing various processes, and making use of various data bases originally not coordinated for the same purpose. It is therefore important to select, develop, or modify models in such a way that they are compatible with one another. Meta Systems (1976) has elaborated factors relevant to evaluating the appropriateness of models for their inclusion in linkages of models. These range from justifications of models in terms of the robustness of their quantitative depictions of physical processes to the ease of directly connecting models. We feel that the following factors have particular importance for this study.

- Complex simulation programs whose application and execution require extensive resources (computers, data, manpower, etc.) usually are not suitable for policy analyses that require a large amount of separate applications. Should a study demand predictions of "short-term" conditions, such as runoff and washoff, because of single precipitation events, then it is clear that these types of models would be necessary.
- Complicated models often do not result in reliable and useful results, considering the difficulties and expense involved in 1) estimating parameters; 2) providing boundary conditions; 3) testing.
- While "complicated" models may provide more "handles" for policy evaluation and permit substitution of fundamental theory for lack of empirical data, the theory in this area is rather primitive, implying that the value of these models is still somewhat low.
- Interpretations of short-term, event-based simulations are more difficult because they require an arbitrary event definition.
- Given available sources of national and regional data (EPA/NES, USDA, etc.), we find it desirable to make as much use as possible of these data in addition to possible local data sources (generally limited) (Walker, 1977; Reckhow, 1977; Meta Systems, 1976).

To test the feasibility of a framework for economic/physical analysis of agricultural practices, it was necessary to start with a relatively simple methodology that yields long-term or seasonal average results; otherwise, the problems associated with complicated models would dominate the analysis and detract from the major task. Our conclusions on feasibility rest on this simple approach. We feel that given currently available data and knowledge of the relevant physical processes, a framework built from complex models would not be feasible or useful in a planning context.

METHODS FOR PREDICTING WATERSHED EMISSIONS[1]

The methods developed to assess the impacts of agricultural practices on nonpoint pollutant loadings are of an empirical nature and are concerned with long-term average emissions, in the spirit of the Universal Soil Loss Equation (Wischmeier and Smith, 1972). Average export rates of the following substances are evaluated in surface runoff and in subsurface drainage:

1) Sediment (sand, silt, and clay fractions);
2) Phosphorus (NH_4F/HCl) extractable particulate and soluble);
3) Dissolved nitrogen; and
4) Dissolved color.

The computed concentrations of these components are assumed to be representative of average water quality conditions in rivers draining the agricultural watershed. This part of the methodology is appropriate for linking with downstream models for the purpose of evaluating quality impacts in impounded waters.

Watershed emissions or loadings are computed as functions of the following characteristics:

1) Surface Soil Properties
   a. Erodibility (K factor in USLE, Wischmeier and Smith, 1972)
   b. Texture (sand, silt, and clay content)
   c. Hydrologic Soil Group (SCS/USDA, 1971)
   d. NH_4F/HCl extractable phosphorus content (in each texture class
   e. Phosphorus distribution coefficient (g extractable P/Kg soil)/ (g dissolved P/m^3 soil solution)
   f. Organic matter content (in each texture class)
2) Watershed/Field Properties
   a. Slope
   b. Slope length
   c. Surface area
   d. Total flow (runoff and drainage)
   e. Rainfall erosivity (R factor in USLE)
3) Agricultural Practices
   a. Cropping factor (C in USLE)
   b. Practice factor (P in USLE)
   c. Nitrogen and Phosphorus fertilization rates
   d. Tillage depth
   e. Crop residue management

Pathways involved in the watershed model are depicted in Figure 3. A brief summary of the essential features of this framework is given below.

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[1] See Appendix B.

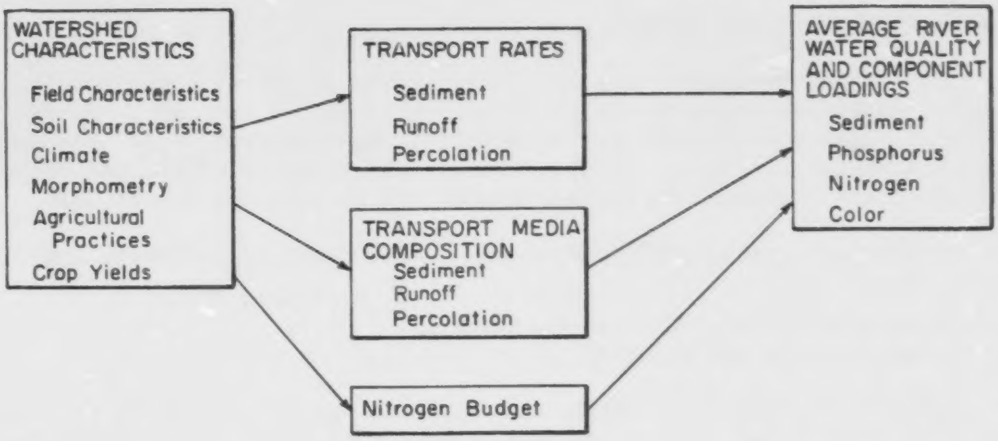
WATERSHED CHARACTERISTICS
Field Characteristics
Soil Characteristics
Climate
Morphometry
Agricultural Practices
Crop Yields
TRANSPORT RATES
Sediment
Runoff
Percolation
TRANSPORT MEDIA COMPOSITION
Sediment
Runoff
Percolation
Nitrogen Budget
AVERAGE RIVER WATER QUALITY AND COMPONENT LOADINGS
Sediment
Phosphorus
Nitrogen
Color

FIGURE 3: PATHWAYS IN THE WATERSHED ANALYSIS

Gross erosion estimates are based upon the Universal Soil Loss Equation (USLE), which has been developed by the USDA for use in the soil conservation area. To make the equation more useful as a tool for evaluating water quality impacts, explicit consideration is given to sediment texture variations. Since the finer fractions of soil generally have higher surface areas per unit mass, they have higher adsorption capacities for various water quality components. By separately considering the clay, silt, and sand fractions in surface soil and eroded sediment, differences in the behavior and transport of these size fractions and their adsorbed pollutants are explicitly represented, both in the watershed and in the impoundment systems. Applying a separate delivery ratio for each texture class permits estimation of sediment and adsorbed pollutant transport to the impoundment.

In each texture class the phosphorus and organic matter contents of sediment particles are assumed to equal those in the corresponding size fraction of surface soil. Because of shallower mixing depths, reduced tillage methods can cause enrichment of surface soils in nutrients and organic matter. These dependencies are explicitly considered in the model framework. Extractable phosphorus contents of the clay, silt, and sand fractions are computed as functions of the respective background levels, fertilization rates, and tillage depths. Similarly, organic matter contents are computed from background levels, crop residue additions, and tillage depths. The computed compositions and delivery rates of sediment in the various size fractions are used to estimate the sediment-bound loadings of these components.

Flow from the watershed consists of two components: surface runoff and subsurface drainage. The sum of the two is assumed to be independent of soil type or agricultural practice. This is essentially equivalent to assuming that average evapotranspiration rates are independent of these factors. Surface runoff is estimated based upon region, Hydrologic Soil Group (SCS/USDA, 1971), and farm practice using methodology developed by Woolhiser

(1976, also EPA/USDA, 1975). The latter is based upon hydrologic simulations using the SCS Curve Number model (SCS/USDA, 1971). Drainage is estimated as the difference between total flow and surface runoff.

Predictions of surface runoff and drainage are used to estimate the transport of dissolved phosphorus and color. Linear adsorption isotherms are employed to estimate 1) the dissolved phosphorus concentration in surface runoff from the average extractable phosphorus content of eroded sediment, and 2) the dissolved color concentration in surface runoff from the average organic matter content of eroded sediment. Dissolved phosphorus and color concentrations in drainage are assumed to be constant at relatively low values (0.3 g/m^3 and $0m^{-1}$, respectively) because they are in equilibrium with subsurface soils which are deficient in extractable phosphorus and organic matter.

In addition to the sediment-bound and soluble phosphorus loadings, explicit consideration is given to the potential for leaching of phosphorus from surface crop residues during snowmelt periods. Because of frozen soil conditions, dissolved phosphorus in snowmelt may not equilibrate (i.e., be adsorbed by) surface soils. Timmons, et al. (1968, 1970) have shown this component to be potentially important when compared with other soluble phosphorus losses from agricultural watersheds. Despite the relative lack of data in this area, leached residue phosphorus has been included because it may be important to evaluate the impacts of minimum tillage methods which tend to create a high potential for such losses by leaving crop residues on the soil surface.

Because nitrogen is generally more mobile in soil systems than phosphorus, estimates of average soluble nitrogen export are based upon mass balance rather than upon computed soil erosion rates and adsorption chemistry. The input terms in the mass balance include fixation, fertilization, precipitation, and soil mineralization. The output terms include crop yield, denitrification, and losses in runoff and drainage. For each soil type and practice, various data sources are used to estimate the net nitrogen input rate, which is defined as the total input minus crop yield. For each soil type, denitrification is estimated as a constant fraction of the net input rate. The total loss in runoff and drainage is then estimated by difference. This scheme ignores export of particulate nitrogen, which is assumed to be not as important as a nutrient source or water quality component (see Appendix B, unattached).

The methodology described above is applicable to a single field or plot of uniform characteristics. In preliminary assessments of agricultural practices, a hypothetical watershed is assumed to be comprised of a number of fields of equal characteristics. This provides a rough measure of the unit emissions and water quality impacts of a given field/soil type/agricultural practice combination. The methodology could be applied as well to a heterogeneous watershed consisting of a number of areas, each with its own set of field/soil type/practice specifications. The effects of heterogeneous watershed characteristics on practice evaluations and conclusions are considered higher level questions which would be addressed subsequent to analysis of homogenous watersheds.

In order to conform to an economic analysis, the watershed model is calibrated to three different field/soil types which are characteristic of the Black Creek Watershed, Indiana. A research and demonstration program sponsored in that watershed by the EPA (Christenson and Wilson, 1976; Lake and Morrison, 1975) has provided some data necessary for calibrating the models. On each soil type, the watershed model is calibrated for evaluation of 11 agricultural practices. Details of the calibrated procedures and results are discussed in Appendix D.

METHODS FOR PREDICTING IMPOUNDMENT WATER QUALITY[2]

In tune with the watershed models, the framework developed for assessing impoundment water quality impacts consists of empirical models which are designed to predict steady-state, seasonal, or long-term average conditions. The following water quality components are considered:

1) sediment concentrations and trapping rates
2) phosphorus concentrations and trapping rates
3) nitrogen concentrations and traping rates
4) mean summer, Secchi Disc transparencies
5) mean summer, epilimnetic chlorophyll-a concentrations

Models are formulated for each of the above components based upon theoretical considerations and the results of previous modeling efforts. They are calibrated and tested empirically using a data base characterizing the behavior of these components in Corn Belt impoundments and compiled from various sources (EPA/NES, 1975; USDA, 1969; ISBH, 1976; USACE, 1977).

The sensitivities of the above water quality components are assessed with respect to annual average input rates, or loadings, of the following substances:

1) water
2) sediment (sand, silt, and clay)
3) phosphorus (total soluble and extractable particulate)
4) nitrogen
5) dissolved color

Additional independent variables of importance include mean depth and impoundment type (reservoir versus natural lake). The pathways in the impoundment water quality analysis are summarized in Figure 4. Essential features are discussed below.

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[2] See Appendix C .

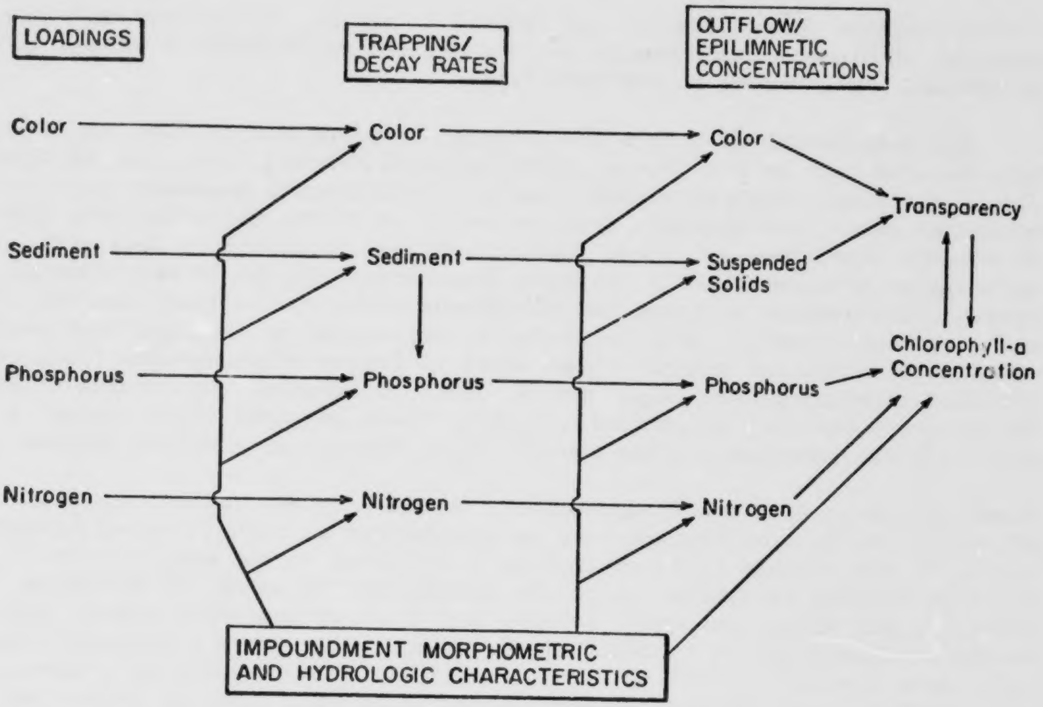
LOADINGS
TRAPPING/ DECAY RATES
OUTFLOW/ EPILIMNETIC CONCENTRATIONS
Color
Sediment
Phosphorus
Nitrogen
Color
Sediment
Phosphorus
Nitrogen
Color
Suspended Solids
Phosphorus
Nitrogen
Transparency
Chlorophyll-a Concentration
IMPOUNDMENT MORPHOMETRIC AND HYDROLOGIC CHARACTERISTICS

FIGURE 4: PATHWAYS IN THE IMPOUNDMENT WATER QUALITY ANALYSIS

Following the watershed model, the behavior of the sand, silt, and clay fractions of sediment are modeled separately within the impoundment. A modification of Bruyne's (1953) empirical curves is used to estimate the trapping efficiency of sediment in each texture class as a function of mean hydraulic residence time. Bruyne's curves are represented reasonably well by a model which assumes a first-order decay process for sediment in a completely-mixed system. Decay rate parameters for clay and silt are selected to match Bruyne's lower and upper envelope curves, respectively. The sand decay rate parameter is selected so that essentially all of the influent sand is trapped. Total sedimentation rate and outflow suspended solids concentration are estimated as the respective sums over texture classes.

The retention, or trapping, of phosphorus is represented by an empirical model which is calibrated using data on phosphorus budgets and sedimentation rates provided for a cross-section of 15 impoundments by the EPA's National Eutrophication Survey (1975) and the USDA (1969). Data indicate that the "effective settling velocity" (Vollenweider, 1969) for total phosphorus in these impoundments is a strong function of sedimentation rate. This suggests that adsorption/sedimentation reactions represent important phosphorus removal mechanisms in these impoundments. The settling velocity is also weakly correlated with mean depth and surface overflow rate. Average outflow phosphorus concentration is estimated from a steady-state mass balance, based upon the average inflow concentration and computed trapping efficiency.

Average outflow concentrations are related to median, summer concentrations measured within the impoundments using empirical relationships derived from 50 EPA/NES impoundments in the Corn Belt.

The development of models for nitrogen trapping and outflow concentration follows that of phosphorus. Data suggest, however, that, unlike phosphorus trapping, nitrogen trapping is not significantly dependent upon sedimentation rate. The nitrogen trapping model is calibrated using data from 50 EPA/NES impoundments. These impoundments are considerably less efficient in trapping nitrogen than in trapping phosphorus. In the 50 impoundments studied, the average nitrogen and phosphorus retention coefficients are .24 and .44, respectively. This is partially attributed to the fact that average nitrogen loadings are roughly three times in excess of phosphorus loadings, relative to algal growth requirements. This conforms to the results of EPA/NES bioassay studies, which indicate that, given adequate light, algae in most of these impoundments are phosphorus, as opposed to nitrogen limited.

Based upon data from eight impoundments provided by the Indiana State Board of Health, Secchi Disc transparency is represented as being inversely proportional to the visible light extinction coefficient in the water column. Light extinction is attributed to the following: 1) water; 2) dissolved color; 3) non-algal, suspended solids; and 4) algal suspended solids (represented by chlorophyll-a concentration). The first term is a constant; the last three are represented as linear functions of the respective concentrations. These relationships are calibrated using data from the region and the general literature. Estimates of dissolved color are based upon the color loadings derived from the watershed model, assuming a first-order decay mechanism for color within the impoundment. Suspended solids concentrations are derived directly from the sedimentation model. Mean summer chlorophyll-a concentrations are estimated using the method described below. The application of a seasonal correction factor to the average annual outflow color and suspended solids concentrations permits estimation of mean summer light extinction coefficients and Secchi Disc transparencies.

Chlorophyll-a is used as an index of primary production, trophic state, and, in some systems, fish production. The model developed for predicting chlorophyll-a levels considers the possible effects of algal growth limitation by light, phosphorus, and/or nitrogen. Expressions for the maximum biomass levels limited by each of the above factors are based upon steady-state solutions of theoretical equations describing algal growth in a mixed surface layer. For a given region and climate the light-limited biomass level is sensitive to epilimnion depth and the portion of the visible light extinction coefficient attributed to water, color, and non-algal suspended solids. The phosphorus- and nitrogen-limited levels are dependent upon mean summer concentrations of total phosphorus and total nitrogen, respectively, in the epilimnion. These limiting biomass expressions are combined in an empirical form to allow for simultaneous limitation of algal growth by more than one factor. The model is calibrated and tested using data from 50 impoundments in the Corn Belt. Analyses of residuals, tests for parameter stability, and evaluations of model performance on an independent data set of 20 impoundments are offered as evidence of model verification.

The calibrated impoundment model has been linked with the watershed model to create a framework for assessing the effects of the 11 different agricultural practices on each of three soil associations in the watershed. Additional factors which must be specified for the assessment include total watershed area, impoundment surface area, and impoundment mean depth. Values of 200 km^2, 5 km^2, and 4 m, respectively, have been selected as being typical of watershed/impoundment configurations in the data set used to develop the impoundment models. With a total flow rate of .25 m/yr from the watershed, the hypothetical impoundment has a surface overflow of 10 m/yr and a mean hydraulic residence time of .4 years.

It should be noted that our evaluations of the relative impact of the practices on impoundment water quality may be somewhat sensitive to this choice of a watershed/impoundment configuration. The methodology could be applied as well to alternative configurations. Because the watershed model is concerned with long-term average loadings, the analytical framework may be less valid for application to impoundments with extremely short hydraulic residence times in which seasonal variations in loading may be important.

SECTION 6

USE OF FARM AND WATER QUALITY MODELS

The results derived in this section are for illustrative purposes and are based on the analytic processes described in the previous sections. In presenting the examples, our intent is to show how the joint use of the farm and water quality models could serve as analytical tools in the development and evaluation of BMP's. The two models are used to illustrate 1) how agricultural practices can be evaluated under existing policies and 2) how government policies could affect the implementation of these practices so that they are conducive to water quality improvements. The evaluation of agricultural practices under current policies uses the 11 selected farm practices listed in Table 2 (as if they constituted a comprehensive set of alternatives currently available to farmers) and shows how the practices impact farm revenues and water quality. These results provide the reference conditions from which alternative policies can be identified and evaluated. Shifts in policies aimed at improving water quality can affect farm revenues and may require government actions such as subsidies, taxes, or restrictions on certain agricultural practices or farm implements. The policies illustrated in this section concern reduction of soil loss and river nitrogen. Future economic conditions that affect the farmer -- apart from environmental regulations -- can also be incorporated in the evaluation by adjusting the farm model. An example is presented showing the impacts of increased energy costs.

CURRENT PRACTICES

Table 4 shows the ranking of the 11 selected farm practices in terms of net revenues for the three farms. The corn-bean-wheat-hay rotation using all farmer-owned equipment has been dropped from the evaluation in favor of custom hiring for wheat and meadow planting and hay harvesting. Use of the farmer-owned equipment option would obscure the merits of the four-crop rotation alternative. The corn-soybean rotations are most profitable based on prices chosen for these commodities in the illustration (i.e., corn, $2.00 per bushel; soybeans, $5.00 per bushel; wheat, $2.50 per bushel; hay, $60 per ton). The chisel plow tillage method would be selected over conventional tillage with a moldboard plow. The maximum profitability for the three farms ranges from $26,100 (the ridge farm) to $13,700 (the uplands farm).

Table 5 ranks the farm practices for the three farms according to soil loss (gross erosion). For the uplands farm the practice which maximized net revenue results in an annual soil loss of 15.2 tons per acre. On this farm losses range from 27.2 tons per acre for corn-soybean rotation with conventional plowing (CB-CV) down to 2.7 tons per acre for corn-soybean-wheat-hay

TABLE 4: NET REVENUE -- 1977 DOLLARS

Farm Practice	Uplands Farm $	 Rank	Ridge Farm $	 Rank	Lowlands Farm $	 Rank
Continuous Corn, Conventional Tillage, without Terracing (CC-CV)	12,800	4(Tie)	23,600	5	22,300	4
Continuous Corn, Conventional Tillage, with Terracing* (CC-CVT)	9,600	9	20,300	10	19,100	6
Continuous Corn, Chisel Plowing, without Terracing (CC-CH)	13,400	3	24,100	4	22,900	3
Continuous Corn, Chisel Plowing, with Terracing (CC-CHT)	10,200	8	20,900	8	19,600	5
Continuous Corn, No-Till Planting, without Terracing (CC-NT)	6,900	11	20,100	11	6,500	11
Corn-Soybeans, Conventional Tillage, without Terracing (CB-CV)	13,500	2	25,800	2	24,400	2
Corn-Soybeans, Chisel Plowing, without Terracing (CB-CH)	13,700	1	26,100	1	24,600	1
Corn-Soybeans, No-Till Planting, without Terracing (CB-NT)	12,200	7	25,100	3	16,600	9
Corn-Soybeans, No-Till Planting, with Terracing (CB-NTT)	8,600	10	21,500	6	13,000	10
Corn-Soybeans Wheat-Hay, Conventional Tillage for Corn only, without Terracing (CBWH)	12,400	6	20,800	9	18,100	7
Corn-Soybeans Wheat-Hay, No-Till Planting, without Terracing (CBWH-NT)	12,800	4(Tie)	21,100	7	17,600	8

*PTO Terraces.

TABLE 5: IMPACT OF FARM PRACTICES ON SOIL LOSS

Farm Practice	Uplands Farm Tons/ Acre	Uplands Farm Rank	Ridge Farm Tons/ Acre	Ridge Farm Rank	Lowlands Farm Tons/ Acre	Lowlands Farm Rank
Continuous Corn, Conventional Tillage, without Terracing (CC-CV)	26.5	10	9.1	10	3.4	10
Continuous Corn, Conventional Tillage, with Terracing (CC-CVT)	18.9	9	6.5	9	2.4	9
Continuous Corn, Chisel Plowing, without Terracing (CC-CH)	12.0	7	4.1	7	1.6	7
Continuous Corn, Chisel Plowing, with Terracing (CC-CHT)	8.5	5	3.0	5	1.1	5
Continuous Corn, No-Till Planting, without Terracing (CC-NT)	7.0	3	2.4	3	0.9	3
Corn-Soybeans, Conventional Tillage, without Terracing (CB-CV)	27.2	11	9.4	11	3.5	11
Corn-Soybeans, Chisel Plowing, without Terracing (CB-CH)	15.2	8	5.2	8	2.0	8
Corn-Soybeans, No-Till Planting, without Terracing (CB-NT)	11.4	6	3.9	6	1.5	6
Corn-Soybeans, No-Till Planting, with Terracing (CB-NTT)	8.1	4	2.8	4	1.0	4
Corn-Soybeans Wheat-Hay, Conventional Tillage for Corn only, without Terracing (CBWH)	4.3	2	1.5	2	0.5	2
Corn-Soybeans Wheat-Hay, No-Till Planting, without Terracing (CBWH-NT)	2.7	1	0.9	1	0.4	1

Notes: Soil Loss = Gross Erosion

Highest Rank, 1 = Minimum Soil Loss

rotation with no tillage (CBWH-NT). These soil loss figures refer to gross erosion rates (before application of delivery ratios). They are proportional, but not directly applicable, to assessment of receiving water impacts.

For the ridge farm the practice which maximizes annual net revenue ($26,100) results in annual soil loss of 5.2 tons per acre. Soil loss on the ridge farm ranges from 9.4 tons per acre for conventional tillage on the corn-soybean rotation (CB-CV) down to 0.9 tons per acre for the no tillage corn-soybean-wheat-hay rotation (CBWH-NT).

For the lowlands farm the farm practice which maximizes annual net revenue ($24,600) has an annual soil loss of two tons per acre. Soil losses on the lowlands farm range from 3.5 tons per acre for the CC-CV and CB-CV practices down to 0.4 tons per acre for the CBWH-NT farm practice.

Rankings of the farm practices with respect to suspended solids, nitrogen, and phosphorus concentrations in the river are shown in Table 6. The farm practices and their net revenues can be compared with these pollutant load contributions in the same manner as illustrated above for soil loss.

As discussed in Section 5, in addition to soil loss, six variables related to water quality were analyzed for the three farms and the 11 farm practices. The results, together with net revenues, are displayed as three sets of bar graphs (Figures 5, 6, and 7). A complete listing of the water quality impacts is presented in Appendix D. The bar graphs are constructed so that increasing pollutant loads or concentrations are shown by higher vertical lengths of the bar; for net revenue vertical length increases with higher returns. The six water quality components displayed and the dimensions used to quantify them are

- Impoundment sedimentation (kg/m^2) [1]
- River nitrogen (g/m^3)
- River phosphorus (g/m^3)
- River light extinction coefficient (m^{-1})
- Impoundment light extinction coefficient (m^{-1})
- Impoundment biomass ($g\ chl\text{-}a/m^3$)

The tables and graphs described above illustrate the types of information produced by the proposed methodology for the case in which government policies are the same as at present. We emphasize that the 11 selected farm practices form an incomplete set of alternatives actually available to a farmer; there are many others. There are also interesting options that do not use synthetic biocides and/or fertilizers. The body of information currently available from Indiana sources is not yet adequate to estimate costs for these options. Nevertheless, estimates are becoming available from other sources because of the increasing use of such techniques among large-scale farmers concerned about the risks of synthetic biocides. If

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[1] kg = kilograms; g = grams; m = meters; yr = years.

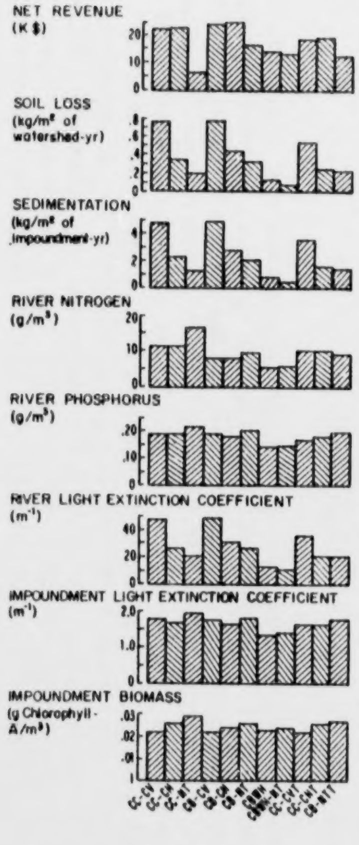

FIGURE 5: COMPARISON OF PRACTICES -- LOWLANDS

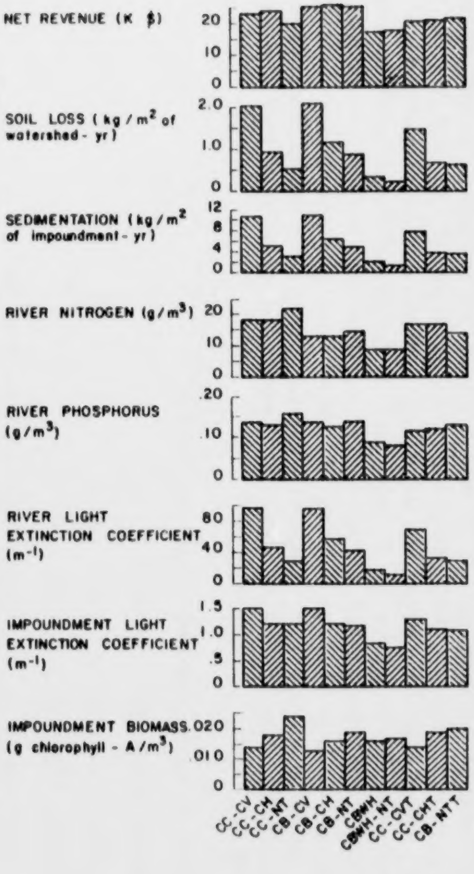

FIGURE 6: COMPARISON OF PRACTICES -- RIDGE

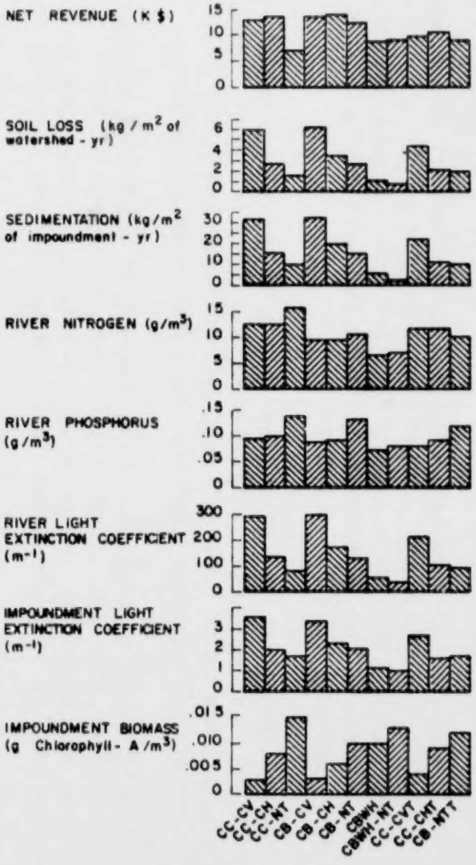

FIGURE 7: COMPARISON OF PRACTICES -- UPLANDS

TABLE 6: IMPACTS OF FARM PRACTICES ON AVERAGE ANNUAL CONCENTRATIONS OF SUSPENDED SOLIDS, NITROGEN, AND PHOSPHORUS IN THE RIVER

Farm Practice	Uplands Farm						Ridge Farm						Lowlands Farm					
	SS kg/m^3	R	N g/m^3	R	P g/m^3	R	SS kg/m^3	R	N g/m^3	R	P g/m^3	R	SS kg/m^3	R	N g/m^3	R	P g/m^3	R
Continuous Corn, Conventional Till., without Terracing (CC-CV)	3.39	10	12.6	9	.09	4	1.11	10	18.5	9	.14	8	.50	10	11.1	9	.19	6
Continuous Corn, Conventional Till., with Terracing (CC-CVT)	2.44	9	11.5	6	.08	2	.81	9	17.1	7	.12	3	.36	9	10.2	7	.17	3
Continuous Corn, Chisel Plow., without Terracing (CC-CH)	1.59	7	12.6	9	.10	8	.54	7	18.5	9	.13	5	.23	7	11.1	9	.19	6
Continuous Corn, Chisel Plow., with Terracing (CC-CHT)	1.15	5	11.5	6	.09	4	.39	5	17.1	7	.12	3	.17	5	10.2	7	.18	4
Continuous Corn, No-Till Plant. without Terracing (CC-NT)	.94	3	15.6	11	.15	11	.33	3	22.0	11	.16	11	.14	3	16.3	11	.21	11
Corn-Soybean, Conventional Till. without Terracing (CB-CV)	3.47	11	9.5	3	.09	4	1.13	11	13.1	3	.14	8	.51	11	7.8	3	.19	6
Corn-Soybean, Chisel Plow., without Terracing (CB-CH)	1.98	8	9.5	3	.09	4	.66	8	13.1	3	.13	5	.29	8	7.8	3	.18	4
Corn-Soybean, No-Till Plant., without Terracing (CB-NT)	1.51	6	10.5	6	.13	10	.51	6	14.7	6	.14	8	.22	6	9.7	6	.20	10
Corn-Soybean, No. Till. Plant, with Terracing (CB-NTT)	1.09	4	9.9	5	.12	9	.37	4	14.0	5	.13	5	.16	4	9.2	5	.19	6
Corn-Soybean-Wheat-Hay, Conventional Till. for Corn only without Terracing (CBWH)	.60	2	6.5	1	.07	1	.21	2	8.7	1	.09	2	.09	2	5.6	1	.14	1
Corn-Soybean-Wheat-Hay, No-Till Plant., without Terracing (CBWH-NT)	.39	1	6.8	2	.08	2	.14	1	8.7	1	.08	1	.06	1	5.8	2	.15	2

Notes: SS = Suspended Solids; N = Nitrogen; P = Phosphorus; R = Rank

Oelhaf's figures (Oelhaf, 1976) are accepted, that cost of farming without the use of synthetic chemicals is within 10 to 15 percent of the cost.

Options for which no illustrative calculations were made include: a fuller use of year-round rotations; integrated pest management; and integrated livestock and cropping operations. Some of these options may contribute to increased economic and environmental stability. We are convinced that it is important to evaluate rotation alternatives (and this includes the CBWH farm practices) and at the same time analyze the role of livestock in the farm unit.

INTERPRETATION OF WATER QUALITY IMPACTS

As shown in Figures 5, 6, and 7, the water quality impacts of agricultural practices vary with field/soil type, water body (river versus impoundment), and specific pollutant. Use of soil loss alone as the criterion for farm practice evaluations can lead to erroneous conclusions because of the importance of various dissolved components in the water and the interactive effects of different processes (e.g., decay, adsorption/desorption, sedimentation). For illustrative purposes, Table 7 lists the relative impacts of two farm practices on water quality components in the river and impoundment for each soil type. Relative impacts are measured as the ratio of the impact

TABLE 7: IMPACTS OF THE MOST EROSIVE PRACTICE (CB-CV) RELATIVE TO THE LEAST EROSIVE (CBWH-NT) ON VARIOUS WATER QUALITY COMPONENTS

Component*	Location	Loading or Concentration Ratio (CB-CV)/(CBWH-NT) Soil Type		
		Lowland	Ridge	Upland
Surface Runoff	Watershed	1.25	4.92	1.76
Gross Erosion	Watershed	10.00	10.00	10.00
Suspended Solids Concentration	River	9.22	8.20	8.92
Suspended Solids Concentration	Impoundment	8.40	6.31	7.80
Sedimentation Rate	Impoundment	9.24	8.30	8.97
Dissolved Nitrogen Concentration	River	1.35	1.50	1.39
Dissolved Nitrogen Concentration	Impoundment	1.22	1.26	1.22
Dissolved Phosphorus Concentation	River	.81	.64	.49
Particulate Phosphorus Concentration	River	7.80	4.29	4.20
Total Phosphorus Concentration	River	1.28	1.61	1.15
Total Phosphorus Concentration	Impoundment	.88	.80	.29
Dissolved Color Concentration	River	.87	1.67	.97
Dissolved Color Concentration	Impoundment	.87	1.67	.97
Light Extinction Coefficient	River	4.58	7.88	8.56
Light Extinction Coefficient	Impoundment	1.65	4.77	5.93
Light Extinction Coefficient**	Impoundment	1.25	2.00	3.63
Chlorophyll-a Concentration**	Impoundment	.90	.80	.25

*Annual averages unless otherwise noted.

**Summer averages.

on water quality of the most erosive farm practice (CB-CV) to that of the least erosive practice (CBWH-NT).

For any given soil type the Universal Soil Loss Equation predicts a ten-fold difference in the gross erosion rates between the two farm practices. The effects on gross erosion are, however, attenuated by the selective erosion and transport of finer sediment fractions. Therefore, the ratio of suspended solids concentrations for the three soil types range from 8.2 to 9.2 in the river and from 6.3 to 8.4 in the impoundment.

Effects of reducing soil erosion are further attenuated in the case of river particulate phosphorus concentrations, and the ratios range from 4.2 to 7.8. River dissolved phosphorus concentrations are actually lower in the more erosive case, as indicated by ratios less than 1.0 in Table 7. This result is attributed to:

1) snowmelt, which leaches dissolved phosphorus from crop residues on the soil surface in the no-till case; and
2) enrichment of surface soil phosphorus levels caused by the shallower tillage and fertilizer incorporation depths characteristic of the no-till case.

Increases in dissolved phosphorus produced by the CBWH-NT farm practice partially offset the particulate phosphorus decreases resulting from that practice. The net result is a 1.2- to 1.6-fold difference in river total phosphorus concentrations, despite a ten-fold difference in gross erosion rates. In the outflow of the impoundment the less erosive farm practice (CBWH-NT) results in higher phosphorus concentrations than the more erosive one (CB-CV). This reversal of effect is attributed to increased impoundment phosphorus trapping efficiency due to higher sedimentation rate. This effect is particularly evident in the relatively steep and phosphorus-deficient upland soils.

Variations in dissolved color also do not follow those of soil loss. Color differences are attributed to differences in 1) runoff, and 2) enriched levels of organic matter in the surface soil, as influenced by tillage depths.

Light extinction coefficients are inversely related to water transparencies and are influenced by turbidity (suspended solids), dissolved color, and in summer algal growth. Variations in suspended solids concentrations are chiefly responsible for the 4.6- to 8.6-fold higher river extinction coefficient values resulting from the more erosive practice. Because of selective trapping of coarse suspended solids and color decay within the impoundment, ratios of annual average impoundment extinction coefficients are reduced to a range of 1.7 to 5.9 for the various soil types. With the algal component included, summer extinction coefficient ratios are further reduced to the 1.2 to 3.6 range.

Use of the less erosive practice results in higher chlorophyll-a concentrations in the impoundment, ratios ranging from .25 to .90. This is attributed to 1) higher phosphorus concentrations in the impoundment (as discussed above), and 2) the reduced effect of light-limitation on algal growth which results when turbidity (suspended solids concentration) is lowered. In the extreme -- the upland case -- implementation of the least erosive practice causes a ten-fold reduction in soil loss, but a four-fold increase in chlorophyll-a concentration. Chlorophyll-a increases in the other soil types are less significant, with ratios ranging from .8 to .9.

These results indicate a possible conflict between the water quality management goals of controlling sedimentation and of eutrophication using the types of farm practices evaluated here. Taking into consideration fish production, higher chlorophyll-a levels could, however, be considered beneficial under certain conditions. Such conditions might include 1) relatively shallow impoundments without extensive stratification; 2) chlorophyll-a concentrations sufficiently low so that occasional major fluctuations in dissolved oxygen (due to algal die-offs and/or respiration during cloudy periods) do not create lethal conditions; and 3) commercial or recreational objectives that emphasize quantity rather than quality or species of fish (i.e., "trash fish" are acceptable). Under these conditions if a model user were to rank fish production as a higher priority than water quality, there would be no conflict. Water quality features that are negatively impacted by algal production -- for example, transparency, taste, odor, or in a stratified impoundment dissolved oxygen concentrations in bottom waters -- would be secondary considerations. Additional data and analyses are needed to provide an adequate basis for interpreting the chlorophyll-a predictions from a benefit point of view. Interpretations would be facilitated by expanding the impoundment water quality model to permit direct estimation of impoundment dissolved oxygen concentrations as influenced by both external (watershed) and internal (photosynthetic) sources of oxygen demand.

With the possible exceptions of phosphorus and eutrophication, control of soil erosion produces beneficial effects on water quality. Nevertheless, as demonstrated above, the relative magnitudes of these effects are considerably smaller than indicated by relative soil loss. In addition, effects on nitrogen concentrations are governed by farm nitrogen budgets rather than soil loss.

The importance of one pollutant compared to another may also shift from watershed to watershed and hence influence the selection of those water quality components of primary importance to the evaluation of the BMP's; that is, the different pollutants should be ranked on the basis of the severity of local water quality issues. In assessing BMP's it seems reasonable to first compare farm practices and their net revenues with respect to the primary pollutants and then incorporate the other pollutants into the analysis.

To illustrate the linking and application of the farm and water quality models, soil loss and nitrogen are used as basic measures of water quality impact in the following discussion. More detailed discussions and interpretations of the water quality impacts of the practices and soil types are included in Appendix D.

FARM PRACTICES AND FUTURE POLICIES

The purpose of linking the farm and water quality models is to evaluate the effects of proposed government policies concerned with agricultural practices on farm income, water pollution loadings, and water quality. For illustrative purposes we consider the following policies.

Conservation Practice Subsidies or Requirements

First, let us consider erosion control subsidies for structural improvements. Terraces are an important soil-saving option. Their total annual cost for our farm of 250 acres is estimated at $6,460, nearly all of which represents construction costs.[2] This is incorporated in Table 4 as a cost totally borne by the farmer, and as a consequence terracing alternatives look less attractive than other alternatives.

A 50 percent terracing subsidy, however, brings the net revenues of the continuous corn chisel plow alternatives on terraced land (CC-CHT) more in line with the highest non-subsidized practice of corn-soybean chisel plow (CB-CH) on non-terraced land. Although the corn-soybean chisel plow practice on terraced land (CB-CHT) was not computed, that alternative would be slightly more favorable than continuous corn with chisel plowing on terraced land (CC-CHT) and would presumably be selected with the 50 percent subsidy. Such a subsidy amounts to $3,230 per 250 acres or about $13 an acre. Soil loss reduction and cost per unit improvement are[3]

	Soil Loss Reduction	Cost Per Ton of Reduction in Soil Loss
Upland:	7 tons/acre	$ 1.90
Ridge:	2 tons/acre	$ 6.50
Lowland:	1 ton/acre	$13.00

Prohibition of Certain Cultivation Practices

The second class of policies -- prohibition of certain tillage practices such as conventional plowing -- would have no apparent economic impact on the farms analyzed here, but could reduce soil loss. This assumes, of course, equal access by a farmer to moldboard and chisel plows. Table 4 directly indicated the cost impact on the farmer of any required shift in crop practice by comparing the forbidden maximum revenue alternative to the permitted maximum revenue alternative.

Comparison of Terracing and Prohibition of Tilling Practices

We may also compare the two policies for reducing soil loss: the $3,230 subsidy per farm; and the prohibition of certain tillage practices. For example, prohibiting moldboard plowing in favor of chisel plowing for continuous corn (CC-CH) or corn-soybean rotations on non-terraced land (CB-CH) reduces the soil loss as follows:

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[2] See Appendix A, Table A-1 for derivation of terrace cost.

[3] The soil loss estimates shown in Table 5 are rounded to the nearest ton in this and subsequent examples.

	Continuous Corn	Corn-Soybean Rotation
Upland:	15 tons/acre	12 tons/acre
Ridge:	5 tons/acre	4 tons/acre
Lowland:	2 tons/acre	1 ton/acre

The substitution of the plowing implements could be accomplished for less cost than the terrace subsidy, and major improvements in soil loss could thus be achieved on the upland farm. If the farmer were subsidized for the acquisition of a $2,150 chisel plow, the cost would be no more than $350 per year; this is the yearly fixed cost for the implement. If the farmer liquidated a moldboard plow as part of a farm implement subsidy package, the cost of the subsidy program could be reduced. From another view, if we assume that the value of each ton of soil retained by terracing is judged to be worth the 50 percent subsidy involved (e.g., on the uplands farm this amounts to $1.90 per ton subsidy), then prohibition of moldboard plowing in favor of chisel plowing on the upland farm is worth approximately $25 per acre for continuous corn and the corn-soybean rotation. This value is about double the $13 per acre value implied by the 50 percent terrace subsidy.

Gross Soil Loss Restrictions

Gross soil loss restrictions are sometimes suggested as watershed planning goals, if not absolute prohibitions. There are numerous ways to apply such restrictions, but for the purposes of this exposition we consider them to apply over each acre of a watershed. Such an interpretation maximizes their impact on costs and on erosion.

Consider, for example, a restriction on gross soil loss of four tons/acre maximum. This implies the following mandated shifts in cropping activities to comply with four tons/acre soil loss.

1. For the upland farm the practice with highest net revenue that meets the soil loss criterion is the corn-soybean-wheat-hay rotation with no tillage (CBWH-NT); additional herbicides are used in the spring to kill the remaining sod before planting corn. (Note that we are considering soil loss as the primary problem; on other grounds use of biocides would probably be rejected in favor of mechanical cultivation which would, of course, increase soil loss to four tons/acre, a bit above the loss expected with the CBWH-NT farm practice). Net revenue decline is

CB-CH = $13,700
CBWH-NT = $12,800

Decline = $ 900 for 250 acres

Reduction in soil loss is about (15 tons/acre for the CB-CH practice - 3 tons/acre for the CBWH-NT practice) = 12 tons/acre.

2. For ridge soils costs to the farmer are somewhat greater, and soil loss reductions considerably smaller. The shift is from corn-soybean with chisel plowing (CB-CH) to corn-soybean with no tillage (CB-NT):

CB-CH = $26,100
CB-NT = $25,100

Decline = $ 1,000 for 250 acres

Reduction in soil loss is only one ton/acre.

3. For the lowlands farm no change from the net revenue maximizing farm practice (CB-CH) would be necessary to meet gross soil loss restrictions of four tons/acre.

Gross Soil Loss Taxes

Gross soil loss taxes are a fourth type of policy of interest in controlling water pollution. For illustrative purposes a tax of 40 cents per ton on soil losses is assumed, and economic impacts are measured.

1. For the uplands farm corn-soybean with chisel plowing (CB-CH) is the net revenue maximizer without tax; soil loss is 15 tons/acre or 3,750 tons/year for the farm. Tax is $1,500, so the new net revenue is (13,700 - 1,500) = $12,000. The CBWH-NT practice has a soil loss of three tons/acre or 250 tons/year, so tax is $300 and new net revenue is ($12,800 - $300) = $12,500. Therefore, net revenues are greater, and the CBWH-NT practice would be chosen.

2. For the ridge farm the impact of a soil loss tax on the revenues from the 11 practices is shown in Table 8. Minor changes in ranking of the net revenues occur as a result of the soil loss tax. However, the advantage of chisel over conventional plowing in terms of dollars net revenue is increased.

TABLE 8: IMPACTS OF SOIL LOSS TAX (1977 DOLLARS)
(RIDGE FARM)

Farm Practice	Net Revenue $	Net Revenue Rank	Soil Loss (tons/acre)	Tax ($.40/ton)	Revenue After Tax $	Revenue After Tax Rank
CC-CV	23,600	5	9	900	22,700	5
CC-CVT	20,300	10	7	700	19,600	11
CC-CH	24,100	4	4	400	23,700	4
CC-CHT	20,900	8	3	300	20,600	9
CC-NT	20,100	11	2	200	19,900	10
CB-CV	25,800	2	9	900	24,900	2
CB-CH	26,100	1	5	500	25,600	1
CB-NT	25,100	3	4	400	24,700	3
CB-NTT	21,500	6	3	300	21,200	6
CBWH	20,800	9	1	100	20,700	8
CBWH-NT	21,100	7	1	100	21,100	7

3. For the lowlands farm the taxes and impacts would be small for a soil loss tax because there is little erosion potential with any of the farm practices.

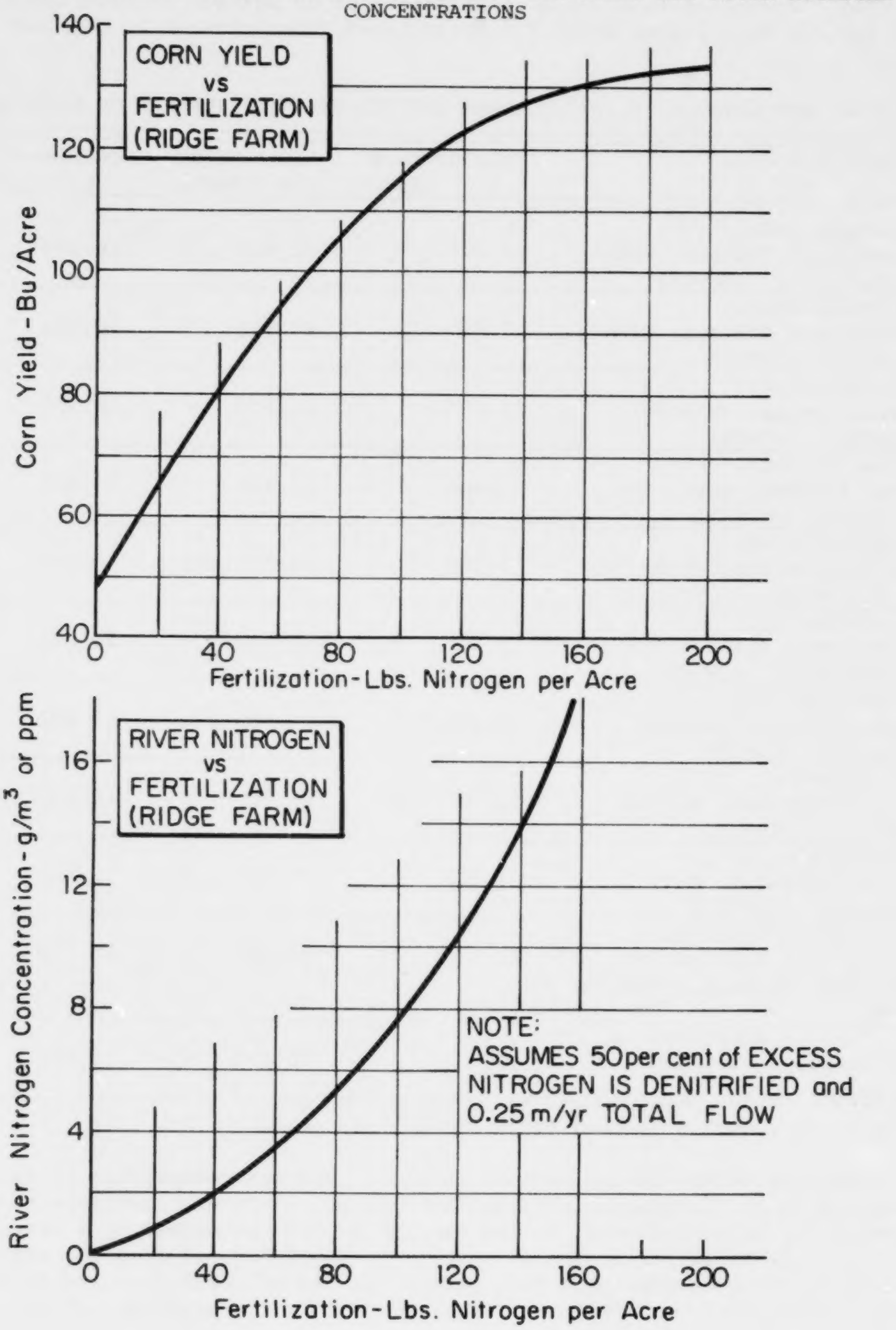
Fertilizer Limitations or Taxes

A fifth policy type considers a fertilizer tax to reduce over-application of fertilizer -- especially nitrogen. The rationale behind such a tax would be as follows. Because of the small slope of the fertilizer response curve in the region of interest (where farmers now operate), a tax can encourage less fertilizer use with modest declines in crop yield and even smaller reductions in net revenue. However, the effects of reduced nitrogen applications are magnified as beneficial impacts on water quality because of the non-linear nature of the water body response to nitrogen. For example, see Figure 8. To evaluate the implications of a fertilizer tax policy, two approaches are illustrated. In the first approach a relatively high tax on nitrogen fertilizer is investigated to determine how changes in farm practices might be induced and how water quality would be affected. In the second approach we show that relatively large reductions in nitrogen use can be attained with small reductions in yield. A fertilizer tax might be used to obtain this result without changing the agricultural practice desired by the farmer.

Nitrogen fertilizer is first assumed to be heavily taxed at $0.07 per pound, representing a price increase of about 50 percent over the price used in the reference cases developed in Appendix A. This tax reduces net revenues by a maximum of $3,400 (on the ridge farm) for the farm practice using the most nitrogen (CC-NT) and by about $900 for the least nitrogen-dependent practices (corn-soybean-wheat-hay rotations). The corn-soybean chisel plow farm practice (CB-CH) is still the highest ranking net revenue practice, but both of the corn-soybean-wheat-hay alternatives have moved up in the ranking, as shown in Table 9. We can estimate water quality implications from data presented earlier in Table 6 on river nitrogen concentrations from the various farm practices. For example, if a sufficiently high fertilizer tax could be imposed so that net revenues for the corn-soybean-wheat-hay no-till farm practice (CBWH-NT) were equal to those for the corn-soybean chisel plow (CB-CH), river nitrogen would be reduced 28 percent for the uplands farm, 34 percent for the ridge farm, and 26 percent for the lowlands farm. This requires a fertilizer tax of $0.13 per pound (or a 100 percent increase in the price of nitrogen to the farmer) for the uplands farm. For the ridge farm the tax required is $0.54 per pound and for the lowlands farm, $0.74 per pound, representing nitrogen price increases to the farmer of 415 percent and 570 percent respectively.

For the second illustrative case the use of nitrogen is somewhat reduced, and the farmer continues to select the same agricultural practice as in the reference case. We have used corn-nitrogen response functions to estimate the yields for different levels of nitrogen application (see Appendix F, unattached), and to illustrate the impacts, we have considered one of the farm practices that is a heavy user of nitrogen -- the continuous corn with chisel plowing (CC-CH). In the Black Creek area on ridge soils, nitrogen

FIGURE 8: EFFECTS OF FERTILIZATION RATE ON LOW YIELD AND RIVER NITROGEN CONCENTRATIONS



application is 160 pounds per acre, resulting in corn yields of 130 bushels per acre. Reduction in nitrogen application of 13 percent is selected and thus reduces corn yields about 2.5 percent and gross revenue by the same amount.

TABLE 9: NET REVENUE -- 1977 DOLLARS (FERTILIZER TAX* IMPOSED ON NITROGEN)

Farm Practice	Uplands Farm		Ridge Farm		Lowlands Farm	
	$	Rank	$	Rank	$	Rank
Continuous Corn, Conventional Tillage, without Terracing (CC-CV)	10,500	7	20,600	5	19,300	4
Continuous Corn, Conventional Tillage, with Terracing (CC-CVT)	7,200	10	17,300	10	16,000	8
Continuous Corn, Chisel Plowing, without Terracing (CC-CH)	11,100	5	21,100	4	19,900	3
Continuous Corn, Chisel Plowing, with Terracing (CC-CHT)	7,800	8	17,900	9	16,600	7
Continuous Corn, No-Till Planting, without Terracing (CC-NT)	4,300	11	16,700	11	3,200	11
Corn-Soybean, Conventional Tillage, without Terracing (CB-CV)	12,400	2	21,600	3	23,100	2
Corn-Soybean, Chisel Plowing, without Terracing (CB-CH)	12,600	1	24,800	1	23,400	1
Corn-Soybean, No-Till Planting, without Terracing (CB-NT)	11,000	6	23,600	2	15,100	9
Corn-Soybean, No-Till Planting, with Terracing (CB-NTT)	7,400	9	19,900	7	11,500	10
Corn-Soybean-Wheat-Hay, Conventional Tillage for Corn only, without Terracing (CBWH)	11,700	4	19,800	8	17,200	5
Corn-Soybean-Wheat-Hay, No Till Planting, without Terracing (CBWH-NT)	12,100	3	20,200	6	16,800	6

*Tax on nitrogen is assumed to be 7 cents per pound.

The resulting impact on net revenue is a four percent reduction. If farmers responded to small changes in fertilizer prices, they would lower their operating costs by an amount equal to the decline in revenue caused by a fertilizer tax. In this illustration the 13 percent decrease desired from the use of nitrogen would be accomplished by a fertilizer tax of about $0.04 to $0.05 per pound. River nitrogen concentration is reduced by approximately 20 percent (i.e., 18.5 g/m^3 to 14.4 g/m^3) by the lowered levels of fertilizer use on the ridge farm. This level of pollutant reduction is explained by Figure 8. It is seen that the corn-nitrogen response curve is relatively flat in the range of interest (i.e., large reductions in nitrogen application result in small reductions in yield). Nevertheless, as the figure shows, the percent reduction in river nitrogen is greater than the reduction in nitrogen applied to the crops.

Manure/Legume Subsidies or Restrictions

The final type of policy evaluation considered is a subsidy for construction of manure storage and handling facilities, or for growing leguminous cover crops to protect the soil and provide crop nitrogen. Because we have not included livestock activities in the methodology developed to date, we consider here only a hay crop subsidy that affects the corn-soybean-wheat-hay rotations. The objective might be to encourage use of such a rotation to conserve soil, nitrogen, and energy.

If the lowlands farm is considered, net revenues for maximum net return -- corn-soybean with chisel plowing (CB-CH) -- is $24,600. Net revenue for the alternative that we wish to encourage -- corn-soybean-wheat-hay (CBWH) -- is $18,00 in the reference case. With a expected yield of four tons per acre and one-quarter of the farm in hay (62.5 acres), the incremental price needed to bring the CBWH practice up to the net revenue level for the CB-CH practice is ($24,600 - $18,100) ÷ (4 x 62.5) = $26 per ton. This is not impossible, especially if an integrated livestock operation is considered. However, a subsidy in that amount ($26 per ton or about $100 per acre) could foster the switch to the CBWH practice at current prices for hay of $60 per ton.

Alternative Futures

One alternative future is a continuation of the trends toward a highly concentrated, factory-like food/fiber production system, characterized by trends listed in Section 1. Aspects of other possible futures evolving out of past and current trends and new forces might include elements from the following list.

1) Stabilization of farm sizes and potential reduction in size of the largest units
2) Reversal of the trend toward absentee ownership
3) Increased labor inputs as energy costs increase
4) Regional and local implement manufacturing operations with focus on the needs of the part-time small farmer
5) Crop price stabilization through international establishment of grain reserves
6) Some reversion to polyculture for economic and ecologic reasons as energy costs increase, to the extent that the environmental problems of synthetic biocides become a problem

7) More use of manure, rotations, and composted urban organics for fertilization and biological control for pest management

8) Increasing integration of livestock activities with feed/food farming as energy costs force more on-farm use of manure as a feed, fertilizer, and energy (methane) source, and as the pollution costs of feedlot operations are passed back to the feedlot operator.

9) State/federal assistance to persons desiring to farm by direct subsidies (soft loans) and innovative land use controls (e.g., purchase of development rights by the state)

10) Adjustments in the organization of marketing and distribution systems to meet the needs of smaller farm operators

11) Consumer and farmer reaction to costs

In order to carry out evaluations that include these kinds of shifts in agriculture, a more complete and complex analysis than was possible in this study is required. However, data exist to explore some of these items and could be incorporated in an automated farm model.

In this study we can illustrate how a properly structured farm model would be used to evaluate farm practices and water quality impacts in a future economic setting. The example concerns increased energy costs, but does not include changes in labor inputs as suggested in the above list, item 3.

Many of the inputs to farm production involve the use of energy derived from oil and natural gas. Farm inputs requiring substantial amounts of energy include fuels used on the farm and energy that is consumed or embodied in the production of fertilizers and biocides. For example, in addition to diesel and gasoline fuels for tractors and combines, corn drying operations consume about 15,000 Btu per bushel for every ten points of moisture reduction. Nitrogen fertilizer requires 20,000 to 25,000 Btu for every pound that is manufactured, while production of biocides requires anywhere from 40,000 to 195,000 Btu per pound depending on their particular formulation.[4]

Prices paid by farmers for fuels and chemicals will continue to rise because of diminishing oil and gas reserves and possibly because of the actions of cartels to create higher oil prices in the long run. It is also likely that decontrol of natural gas prices will be implemented in the next five to ten years. It seems reasonable to assume that equal prices will eventually be established based on Btu content. Farm practices that are more heavily dependent on mechanization and use of chemicals will be impacted most severely compared to the less energy-dependent cultivation practices.

We have postulated an economic future for 1985. Prices for tractor and combine fuel, grain drying operations, and the various chemicals bought by the farmer will be substantially higher. In the case illustrated here we assumed 1985 energy prices will be approximately double the 1977 prices,[5] while prices for other inputs remain constant. This projected increase is stated in constant 1977 dollars and therefore does not include inflationary trends.

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[4] Personal communication, D. Pimental, Cornell University, November, 17, 1977.

Maintaining the same 11 farm practices previously described results in increased cost of farm operations ranging from $10,000 to $30,000 annually, depending on the practice. This range corresponds to a 30 to 65 percent increase over 1977 costs. Net returns are, of course, drastically affected. Needless to say, profitability depends on revenues as well as costs. We have not, however, attempted to project prices received by the farmer for corn, soybeans, wheat, and hay; even if this had been done, it is possible that some of the farm practices would no longer appear to be financially viable. Since we are interested in the potential impacts of farm practices on water quality as induced by profitability considerations, it is sufficient to evaluate changes in farm costs without attempting to adjust gross revenues. A more complex projection would consider substitution, technological change, and farm scale change effects that are beyond the scope of the present effort.

Table 10 shows the impacts from the future energy prices. On all three farms the corn-soybean-wheat-hay rotations indicate their lesser dependency on energy by an upward shift in their net revenue rankings compared to the reference cases with 1977 energy prices. The impacts are most dramatic on the uplands farm. The CBWH-NT and CBWH net revenues are ranked one and two respectively, compared to a 1977 ranking of four and six. Moreover, the annual soil loss with these two farming practices is four tons per acre or less, whereas the highest net revenue practice in 1977 (CB-CH) has a soil loss of 15 tons per acre on the uplands farm.

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[5] Energy Resources, Inc., "Data Resources Outlook for the U.S. Energy Sector: Control Case," Energy Review. Summer, 1977.

TABLE 10: EFFECT OF FUTURE ENERGY PRICES (CONSTANT 1977 DOLLARS)

Farm Practice	Uplands				Ridge				Lowlands			
	1985 net revenue* $	rank	1977 net rev. rank	soil loss rank	1985 net revenue* $	rank	1977 net rev. rank	soil loss rank	1985 net revenue* $	rank	1977 net rev. rank	soil loss rank
Continuous Corn, Conventional Tillage, without Terracing (CC-CV)	- 8,100	8	4	10	+ 800	7	5	10	- 1,500	7	4	10
Continuous Corn, Conventional Tillage, with Terracing (CC-CVT)	-11,700	10	9	9	- 2,800	9	10	9	- 5,000	10	6	9
Continuous Corn, Chisel Plowing, without Terracing (CC-CH)	- 7,400	7	3	7	+ 1,500	6	4	7	- 800	6	3	7
Continuous Corn, Chisel Plowing, with Terracing (CC-CHT)	-11,000	9	8	5	- 2,100	8	8	5	- 4,400	9	5	5
Continuous Corn, No-Till Planting, without Terracing (CC-NT)	-19,900	11	11	3	- 6,000	11	11	3	-22,500	11	11	3
Corn-Soybeans, Conventional Tillage, without Terracing (CB-CV)	- 300	4	2	11	+11,600	2	2	11	+ 8,800	2	2	11
Corn-Soybeans, Chisel Plowing, without Terracing (CB-CH)	- 80	3	1	8	+11,800	1	1	8	+ 9,000	1	1	8
Corn-Soybeans, No-Till Planting, without Terracing (CB-NT)	- 3,200	5	7	6	+ 9,300	4	3	6	- 400	5	9	6
Corn-Soybeans, No-Till Planting, with Terracing (CB-NTT)	- 7,000	6	10	4	- 5,300	10	6	4	- 4,200	8	10	4
Corn-Soybeans-Wheat-Hay, Conventional Tillage for Corn only, without Terracing (CBWH)	+ 50	2	6	2	+ 8,200	5	9	2	+ 4,900	4	7	2
Corn-Soybeans-Wheat-Hay, No-Till Planting, without Terracing (CBWH-NT)	+ 2,600	1	4	1	+10,700	3	7	1	+ 7,600	3	8	1

Notes: Highest soil loss rank, 1 = minimum soil loss.
Highest revenue rank, 1 = maximum net revenue.

*Output prices assumed to remain at 1977 level.

SECTION 7

IMPACTS ON DOWNSTREAM USERS

As discussed in Section 6, the results of combining the farm, watershed, and impoundment models and applying them to a case study area show that the use of alternative farm practices on different soils has different water quality impacts. Changes in water quality caused by changing farm practices have impacts on downstream water users. To estimate these impacts, changes in water quality must be related to measurements of value to people. If this could be accomplished, the beneficial impacts of alternative agricultural practices on downstream users could be compared with the costs (management, environmental, and social, to farmers and others) of instituting alternative farming practices. The decision maker could then decide if the beneficial impacts (benefits) of instituting a particular policy are worth the costs. This is, however, a difficult step, especially since we are concerned here with more than one water quality parameter and many downstream users.

A benefit estimation study is a major undertaking in terms of time and expense and has therefore seldom (or never) been done at the comprehensive level desirable for estimating the impacts of changes in more than six water quality variables on a multiple-use impoundment. Table 11 shows alternative methodologies that are appropriate for measuring different water quality benefits. Depending on the use of the water and the surrounding land uses, certain impacts are of more or less interest to groups of people concerned with water quality. Therefore, it is necessary to determine which groups are likely to derive the most benefit from which aspects of improved water quality.

As an example of the interests of different groups, let us assume that the watershed in which the farmland is located drains into a small stream used by local sport fishermen in the spring. Downstream is an impoundment created for the purposes of water supply, flood control, and recreation. The impoundment is a major recreational and aesthetic attraction in the region, attracting people from surrounding counties to swim, boat, fish, and picnic. Let us also assume that a town uses the reservoir to supply water for drinking and other purposes. Some benefit categories of interest in this case are: human health, municipal water supply, flood control, ecology, recreation, aesthetics, and the local economy. The methods of benefit estimation vary according to the benefit categories of interest and have been discussed and evaluated according to the criteria outlined in Appendix E. The following paragraphs briefly indicate possible research approaches for each of the above categories.

TABLE 11: COMPARISON OF METHODOLOGIES TO MEASURE WATER QUALITY BENEFITS

	Benefit Categories										
	aesthetics	recreation	property values	human health	commercial fishing	agriculture	municipal water supply	industrial water supply	dredging (navigational, flood control)	ecology	local or regional economy
time budget	X	X									
bidding games	X	X		X							
travel costs		X									
marginal costs				medical costs & lost earnings			treatment production costs	treatment production costs	X		
net factor income					yield change x price	yield change x price					
market study			X								
non-dollar measurement	ranking	ranking								change in habitat	
input/out-put model											X
alternative cost										cost to reproduce	

Human Health. Epidemiological data must be gathered and analyzed to relate morbidity and mortality rates to drinking water nitrate or biocide levels or both. Health effects would then be related to their value to people either by: 1) calculating a dollar value for medical costs and lost earnings for each rate of morbidity and mortality; 2) surveying the relevant population using a bidding game approach to determine aggregate willingness-to-pay to avoid each level of health effect; or 3) a combination of both of these methodologies.

Municipal Water Supply. Variations in treatment cost, including equipment and maintenance costs, must be estimated for alternative pollutant (sediment, etc.) levels.

Flood Control. Sediment deposition affects frequency and severity of flooding. This relationship also must be specified, and the cost of related flood damage calculated.

Ecology. One possible approach ranks habitat changes that affect growth of organisms caused by water quality changes. Diversity is one criterion used to define this ranking. Another approach would be to calculate the cost of reproducing the function that the ecology of the region provides and that would be altered by water quality changes.

Recreation. Recreation covers both contact activities such as swimming, and non-contact activities such as boating. The travel-cost method is one of the accepted methodologies available to construct a demand function dependent on alternative levels of water quality, using data on variations in distance traveled to recreation sites as a surrogate price for the activity. This method may not be the best choice, since in one example most of the users of this impoundment are local and do not travel long distances.

Another approach, the bidding game, relies on survey data to indicate the highest amount people would be willing to pay for an improvement in water quality. The bidding can be tied into an appropriate mechanism such as a water bill, a recreation fee, or a tax. Results, however, seem dependent on assumed starting bids.

In the time budget approach, also using a survey format, respondents describe their activities and expenses during a certain time period -- a week, for example -- which are then matched with certain levels of environmental quality. This information is used to build a demand curve.

For sport fishing, another important recreational activity, benefits accruing to fishing have been related to a fish response model. This model simulates fish responses in terms of quantity and type to water quality changes. With commercial fishing, benefits could be derived by translating the particular fish population into a dollar measure of changes in income, assuming constant prices. Sport fishing variables other than success are important to the recreational experience. In might be possible to combine the fish response device with one of the survey methods described above to obtain information on sport fishing benefits.

Aesthetics. The aesthetic and visual aspects of the river or impoundment water quality are determined by attributes such as color, depth perception, the existence of weeds, etc.

One approach would be to consider aesthetics along with recreation benefits in a time-budget or bidding game survey. The population sample surveyed would then be expanded to include non-recreationists. Typically, ranking methods have been used to ascertain the value of the aesthetic qualities of natural resources. One difficulty is that the aesthetic value of a water body is greatly influenced by its surroundings and characteristics other than water quality. A good non-monetary ranking system used in conjunction with the survey methods would be valuable as a reliability check.

Local Economy. An input/output model could be constructed for the regional economy surrounding the impacted water body. Increased expenditures generated by recreationists or tourists (see above) in response to changes in water quality could be used in the model to calculate the resulting increase in household income and local production.

We have outlined possible elements of a comprehensive benefit estimation methodology. It is clear that such a study would require significant time and resources to implement and would present many empirical difficulties. As an alternative, we would like to present a simplified version that qualitatively assesses the direction of benefits resulting from water quality changes induced by the alternative farming practices. This is considered a substitute for the major effort which would be required to implement a quantitative benefit estimation methodology.

Table 12 indicates which water quality components impact which benefit categories. A minus sign indicates that an increase in the water quality measurement has a detrimental effect on the specified benefit group; for example, an increase in nitrogen concentration in drinking water is potentially harmful to human health. A zero indicates that an increase in the parameter is of no importance to the benefit category. For instance, the same increase in nitrogen concentration just mentioned would not impact dredging operations in the impoundment. A water quality measurement increase which has a positive impact on a benefit category is indicated by a plus sign. Increasing impoundment biomass, for example, might improve sport fishing, since more food might increase the available fish population.

TABLE 12: IMPACTS ON BENEFIT CATEGORIES OF WATER QUALITY COMPONENTS*

	Water Quality Components					
Benefit Categories**	Impoundment Sedimentation (kg/m^2)	Impoundment Sediment outflow Concentration (kg/m^3)	River and Impoundment Nitrogen (g/m^3)	River Light Extinction Coefficient (m^{-1})	Impoundment Light Extinction Coefficient (m^{-1})	Impoundment Biomass (g chlorophyll-a/m^3)
human health (drinking water)	0	-	-	-	-	-
municipal water supply	-	-(+)	-	-	-	-
flood control	-	0	0	0	0	0
ecology	-	-	-	-	-	-
recreation						
sport fishing	-	-	0	-	-	+(-)
contact	0(-)	-	-	-	-	-
non-contact	0(-)	-	0	-	-	-
aesthetics	0(-)	-	0	-	-	-
local economy	-	-	-	-	-	-(+)

*The effect on a benefit category of an increase in any parameter is noted as follows: detriment = -; no effect = 0; benefit = +.

**See text for explanation of benefit categories.

There are several cases in which the impact of a water quality change on a benefit category is not totally clear. These are noted by alternative signs in parentheses. Four such cases are evident in Table 12:

1) Sedimentation in a municipal water supply is mainly detrimental because it causes turbidity, carries chemicals and other toxic materials, and, if it occurs in high concentrations, must be removed during treatment. On the other hand, sediment does tend to adsorb odor and taste-producing chemicals which might otherwise require artificial flocculation (coagulation). This possible benefit is considered to be less important than the detriment, and therefore a minus sign is used to show the dominant effect.

2) An increase in impoundment biomass may have a positive effect on sport fishing, since it means an increase in food supply for fish and hence in fishing success. With excessive amounts of algal growth, however, bottom conditions deteriorate and dissolved oxygen levels decrease, causing a decrease in desirable fish species, such as trout, and an increase in trash fish, which survive better under such conditions. This may ultimately have a negative impact on sport fishing. In our case example, however, we assume that increasing biomass levels can be viewed as beneficial to sport fishing.

3) The local economy benefit category is dependent on the benefits to tourists and recreationists, and therefore the water quality impacts observed will be positive or negative according to the impacts on the recreation and aesthetic benefit categories. Since an increase in biomass has a negative impact on contact and non-contact recreation as well as aesthetics, it will most probably have a negative impact on the local economy despite its generally positive impact on sport fishing. The opposite would be true only if much of the local economy were dependent on an influx of fishermen, which we did not assume.

4) Sedimentation reduces the holding capacity of an impoundment. When this effect is slight and the impoundment is large, there will be insignificant impacts on contact and non-contact recreation and aesthetics -- assumed in Table 12. However, in some cases sedimentation could be a very grave problem in an impoundment, causing it to fill in and cease to exist.

It is clear from Table 12 that with the possible exception of the beneficial impact of higher biomass levels on sport fishing, all categories are either not influenced or negatively influenced by an increase in any of the water quality components.

In order to compare the practices from the downstream users' point of view, we need to select a base case; this is the case option producing the highest net revenue (the corn-soybean rotation using chisel plowing), essentially assuming that the farmer is a maximizer of net revenue. Figures 9, 10, and 11 depict the relative water quality and net revenue impacts (measured as percentage increases or decreases relative to the base case) of the other ten practices on the various soil types.

FIGURE 9: PERCENT CHANGE OF HIGHEST REVENUE FACTOR -- LOWLAND

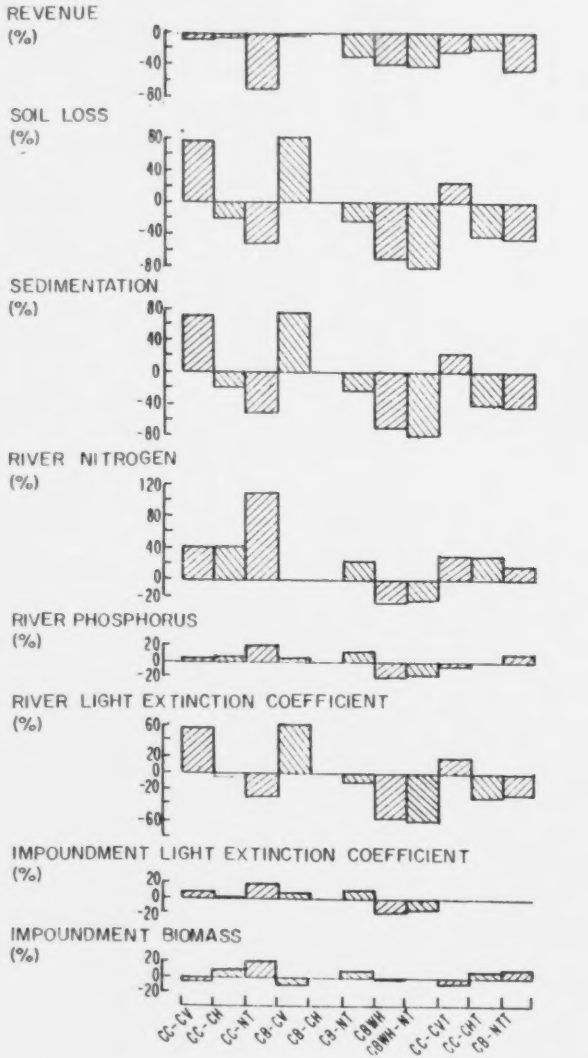


FIGURE 10: PERCENT CHANGE OF HIGHEST REVENUE FACTOR -- RIDGE

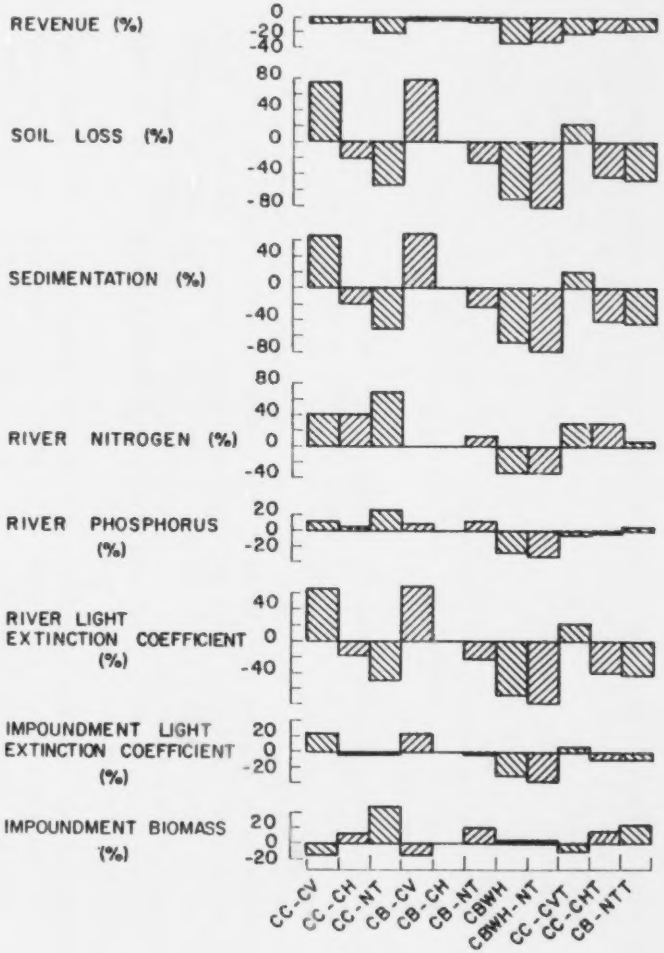
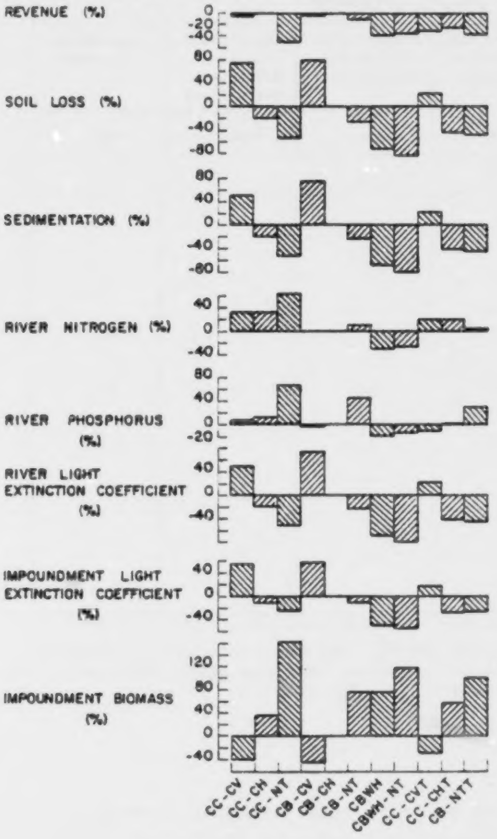


FIGURE 11. PERCENT CHANGE OF HIGHEST REVENUE FACTOR--UPLANDS



The downstream benefits of alternative farming practices can be qualitatively compared by mapping the quantitative practices and water quality relationships depicted on Figures 9, 10, and 11 onto the qualitative water quality benefit relationships presented in Table 12. Results are summarized in Table 13 for a comparison of the corn-bean-wheat-hay rotation with the assumed base case (corn-soybean rotation with chisel tillage). The rows in Table 13 correspond to different benefit categories, and the columns to different water quality components. As in Table 12, a positive sign indicates that switching from the base case to the compared practice produced a beneficial impact on the corresponding benefit category. The percentage changes in the various water quality components, necessarily considered in evaluating the results, are also listed in Table 13. The only negative impact of switching to the CBWH rotation is related to the impoundment biomass column -- namely, the impact on sport fishing; however, the mere three percent change in biomass indicates that this negative impact might be minor relative to the positive impacts on sport fishing operating through the other water quality components. The most pronounced beneficial impacts are due to reductions in impoundment sedimentation, impoundment suspended solids concentrations, and river extinction coefficients.

In order to develop an aggregate estimate of the impact of any practice on any given benefit category, the relationships between the levels of the various water quality components and the degree of benefit derived by each user would have to be defined.

This could be done possibly using an approach similar to that taken by Meta Systems in assessing the impact of each alternative canal route of the proposed Cross Florida Barge Canal on all the habitats of the canal zone -- as perceived by each interest group.[1] However, data constraints do not permit these estimates , at least at this stage of the methodology development.

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[1] Meta Systems Inc, The Overall Assessment for the Cross Florida Barge Canal Project. Contract No. DACW 17-75-C-0077, U.S. Army Corps of Engineers, Jacksonville District, Cambridge, Massachusetts, May, 1976.

TABLE 13. RELATIVE IMPACTS OF CBWH PRACTICE ON WATER QUALITY COMPONENTS AND BENEFIT CATEGORIES FOR THE LOWLAND SOIL TYPE **

	Water Quality Components					
	Impoundment Sedimentation	Impoundment Sediment Outflow Concentration	River and Impoundment Nitrogen	River Light Extinction Coefficient	Impoundment Light Extinction Coefficient	Impoundment Biomass
Percent Increase from Base Case (CBWH) *	-70%	-69%	-20%	-59%	-18%	-3%
Benefit categories ***	BENEFIT IMPACTS					
human health (drinking water)	0	+	+	+	+	+
municipal water supply	+	+	+	+	+	+
dredging (flood control)	+	0	0	0	0	0
ecology	+	+	+	+	+	+
recreation						
sport fishing	+	+	0	+	+	-
contact	0	+	+	+	+	+
non-contact	0	+	0	+	+	+
aesthetics	0	+	0	+	+	+
local economy	+	+	+	+	+	+

* The base case is the highest revenue producing alternative (CB-CH). The effect on a benefit category of an increase in any parameter compared to the base case is noted as follows: detriment = -; no effect = 0; benefit = +. A decrease would have the opposite sign (See Table 11).

** See farm model discussion for definition of farming practices.

*** See text for explanation of benefit categories.

If an aggregate measure can be derived within each benefit category, the next level of analysis is the traditional benefit analysis striving for one scalor to the extent feasible. This number would be the sum of the water quality impacts (as weighted by each group) aggregated across all the groups. As discussed in the analysis of the Cross Florida Barge Canal and other projects, the major difficulty, perhaps the ultimate reason for the inapplicability of the approach at the local/regional level, is the selection of the various weighting factors (based on political, social, and economic aspects) permitting the necessary aggregation. Furthermore, the fact that different groups follow their interests implies that computing an overall scalor might not be helpful in evaluating alternative agricultural practices and their various impacts.

If an aggregate measure of benefits to downstream users could be defined, comparison with the aggregated costs incurred by upstream farmers would lead to a measure of net benefits. However, considering the fact that upstream users incur different costs dependent upon pertinent policies, locations, soil, etc., the aggregate upstream cost does not reflect realities of conflict among farmers. These questions have not yet been adequately addressed within the overall framework.

Rather than attempting to account for all the considerations just mentioned, we have completed in Table 14 a simple summary of the relative impacts of 11 farm practices (each developed in a table similar to Table 13) on the benefit categories of interest. No attempt has been made here to weigh water quality components or benefit categories. We feel that while there are certain gains to be made in pursuing the traditional approach, it may be most worthwhile in the short run to examine possible non-monetary approaches that allow for various weighting schemes to compare upstream and downstream benefits and de-benefits associated with various uses (users).

TABLE 14: SUMMARY OF RELATIVE IMPACTS OF FARMING PRACTICES ON BENEFIT CATEGORIES

Soil Type: Lowlands	Farming Practices*										
Benefit Categories**	CC-CV	CC-CH	CC-NT	CB-CV	CB-CH	CB-NT	CBWH	CBWH-NT	CC-CVT	CC-CHT	CB-NTT
human health (drinking water)	1(+)[+] 1(0) 4(-)	2(+) 1(0) 3(-)	2(+) 1(0) 3(-)	1(+) 2(0) 3(-)	6(0)	2(+) 1(0) 3(-)	5(+) 1(0)	4(+) 2(0)	1(+) 2(0) 3(-)	2(+) 2(0) 3(-)	2(+) 1(0) 2(-)
municipal water supply	1(+) 5(-)	3(+) 3(-)	3(+) 3(-)	1(+) 1(0) 4(-)	6(0)	3(+) 3(-)	6(+)	5(+) 1(0)	1(+) 1(0) 4(-)	3(+) 1(0) 1(-)	3(+) 3(-)
dredging (flood control)	5(0) 1(-)	1(+) 5(0)	1(+) 5(0)	5(0) 1(-)	6(0)	1(+) 5(0)	1(+) 5(0)	1(+) 5(0)	5(0) 1(-)	1(+) 5(0)	1(+) 5(0)
ecology	1(+) 5(-)	3(+) 3(-)	3(+) 3(-)	1(+) 1(0) 4(-)	6(0)	3(+) 3(-)	6(+)	5(+) 1(0)	1(+) 1(0) 4(-)	3(+) 1(0) 2(-)	3(+) 3(-)
recreation sport fishing	1(0) 5(-)	4(+) 1(0) 1(-)	4(+) 1(0) 1(-)	1(0) 5(-)	6(0)	4(+) 1(0) 1(-)	4(+) 1(0) 1(-)	4(+) 2(0)	2(0) 4(-)	4(+) 2(0)	4(+) 1(0) 1(-)
contact	1(-) 1(0) 4(-)	2(+) 1(0) 3(-)	2(+) 1(0) 3(-)	1(+) 2(0) 3(-)	6(0)	2(+) 1(0) 3(-)	5(+) 1(0)	4(+) 2(0)	1(+) 2(0) 3(-)	2(+) 2(0) 2(-)	2(+) 1(0) 3(-)
non-contact	1(+) 2(0) 3(-)	2(+) 2(0) 2(-)	2(+) 2(0) 2(-)	1(+) 2(0) 3(-)	6(0)	2(+) 2(0) 2(-)	4(+) 2(0)	3(+) 3(0)	1(+) 3(0) 2(-)	2(+) 3(0) 1(-)	2(+) 2(0) 2(-)
aesthetics	1(+) 2(0) 3(-)	2(+) 2(0) 2(-)	2(+) 2(0) 2(-)	1(+) 2(0) 3(-)	6(0)	2(+) 2(0) 2(-)	4(+) 2(0)	3(+) 3(0)	1(+) 3(0) 2(-)	2(+) 3(0) 1(-)	2(+) 2(0) 2(-)
local economy	1(+) 5(-)	3(+) 3(-)	3(+) 3(-)	1(+) 1(0) 4(-)	6(0)	3(+) 3(-)	6(+)	5(+) 1(0)	1(+) 1(0) 4(-)	3(+) 1(0) 2(-)	3(+) 3(-)

*See farm model discussion for definition of farming practices.

** See text for explanation of benefit categories.

+Sum of the effects on a genefit category of a change from the base case (CB-CH) to another farming practice. Six water quality components are evaluated. Numbers indicate the number of water quality component changes that have a positive, negative, or no effect on the benefit category. Detriment = -; no effect = 0; benefit = +.

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Appendix A

Farm Model

Introduction

The development of the farm budget is presented in this appendix. The model assumes that the farmer is a profit maximizer and will choose the farming practice which gives him the highest net revenue. The purpose of the budget approach is to show the effects on net farm revenue of different farming practices considered because of their potential for reducing nonpoint source pollution for agriculture. This model is based on a farm budget developed by Dr. Klaus Alt of Iowa State University, Ames, Iowa and discussed in Appendix C "Economic Analysis Methodology" of USDA and U.S. EPA, Control of Water Pollution from Cropland, Vol. II.

The farm budgets shown here are based on eleven farming practices which are appropriate for use on farms in the Black Creek area of northeastern Indiana near Fort Wayne. The most commonly used cropping practices in the case study are are included, corn and corn-soybean rotation, and the most common method of cultivation, conventional tillage, which includes fall plowing with a moldboard plow. In addition to these practices, two reduced tillage practices, chisel tillage and a no-till option, are applied to these two cropping patterns to examine their effects on net revenue and water quality. Chisel tillage involves shredding stalks and chisel plowing in the fall and disking in the spring. The no-tillage option is defined as shredding stalks in the fall and planting in the spring using a no-till planter. A more extensive crop rotation of corn-soybean-wheat-meadow, involving field cover crops as well as row crops, is also examined. This rotation is considered with two tillage options, one in which the meadow is plowed in the fall using a moldboard plow before planting the corn in the spring and the other in which herbicides are used in the spring to kill the remaining sod before planting corn with a no-till planter. Terracing, a structural erosion control measure, was added to three of the above eight practices, continuous corn, both conventionally tilled and chisel tilled, and a no-till corn-soybean rotation.

Farm budgets were developed for three typical farms of two hundred and fifty acres each located on three soil types. The soil types, upland, ridge and lowland, were selected as representative of soils in the case study region. The uplands can be characterized as a Blount-Morley-Pewamo association, the ridge as a Rensselaer-Whitaker-Oshtemo association and the lowlands as a Hoytville-Nappanee association. Some of the farming practice costs vary depending on which soil type the farm is located.

Tables A-1 through A-10 show detailed costs for the inputs, ranging from equipment to seeds, required for using each of the eleven practices on each of the farms. Table A-11 shows expected yield and gross revenue for each practice and Table A-12 presents a summary of all the costs as well as gross and net revenue for each practice on each soil type. The practices are ranked in terms of net revenue in Table A-12 and in terms of soil loss in Table A-13.

Following this presentation of the basic farm budget model for the eleven practices considered is the development of six alternative situations and policies. The use of the model here is to show how these alternatives impact net farm revenue and in turn affect the choice of the farmer. Ultimately the implementation of any agricultural policy will rest on the decisions made by the individual farmer.

The assumption is made in Alternative A that the farmer hires custom operators to carry out certain tasks in the two extensive crop rotation practices considered. This results in increased net return for these two practices. The net revenues developed for these two practices in this alternative are used in Section 6 of the main report as part of the base case. Custom hiring was not assumed in Alternatives B through F, following, which are preliminary.

Alternative B represents a future scenario in which energy prices more than double compared to other prices. This case was developed to illustrate how the farm model can be used to examine the robustness of agricultural policies under alternative futures.

The last four alternatives, C, D, E and F illustrate the effects of agricultural policies which might be implemented to encourage farmers to adopt practices which are beneficial to water quality or which are aimed directly at controlling farm factor inputs which are detrimental to water quality.

Table A-1. Terraces

Terrace costs were calculated on the basis of cost per linear foot of terrace as experienced in the Black Creek Project. This includes the cost of associated tile drains. Since the slope length is relatively short compared to the terrace spacing so that there is one terrace per slope, as we assumed here, then the approximate number of feet of terrace per acre is calculated by dividing 43,560 (the number of square feet per acre) by the terrace spacing. This is the method suggested in the Midwest Farm Planning Manual (Third edition, ISU Press, Ames, Iowa, 1973, revised 1975).

While not the case in our study, if more than one terrace per acre is specified, as in Table A-1, Appendix C, Control of Water Pollution from Cropland, then the number of feet of terrace per acre is estimated by dividing 43,560 by the slope length and multiplying by the number of terraces per slope. Other items were calculated as indicated in the footnotes.

It was assumed for simplification purposes that every acre was terraced. It should be noted that the values used for terrace spacing, slope length and cost per foot of terrace were generalizations applied to the whole watershed area, and would vary considerably from farm to farm in actual practice.

Table A-1

Terrace Costs*

Item	Amount
Terrace spacing, feet**	180
Slope length, feet*	300
Number of terraces per slope*	1
Feet of terrace per acre	242
Construction cost per foot terrace ($)***	1.00
Construction cost per acre ($)	242
Prorated construction cost ($)[+]	25.81
Maintenance cost, foot ($)[++]	0.00011
Maintenance cost, acre ($)	0.03
Yearly terrace charge per acre ($)	25.84
Total yearly terrace charge (250 acres) ($)	6,460.00

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* Assume slope length 300 feet and one terrace per slope.

** Daniel McCain, District Conservationist, Allen County Soil Conservation District, estimate for Black Creek Watershed.

*** James Lake, Black Creek Project Administrator, estimate for Black Creek Watershed ($1.00-$1.25). Joseph Pedon, Agronomist, Indiana Soil Conservation Service, Indianappolis, recommended use of lower figure to account for increased contractor experience over time.

[+] Assume 15 year life (from Daniel McCain, District Conservationist, Allen County Soil Conservation District) and interest at 8 percent. Average yearly interest = [(initial cost + salvage value)/2] x i rate. Prorated construction cost = average yearly interest + [(initial cost)/(economic life)]. Assume salvage value = 0.

[++] Assumed one-half of maintenance cost used in Sidney James (ed.), Midwest Farm Planning Manual, Third edition, ISU Press, Ames, Iowa, 1973, revised 1975, p. 34, after discussion with Joseph Pedon, Agronomist, Indiana Soil Conservation Service.

Table A-2. Machinery Fixed Costs

Specifications for the farm equipment for each farming practice were developed using the equipment listed in Table 2, Appendix C, Control of Water Pollution from Cropland as a base, with modifications appropriate for current farming practices in northeastern Indiana. Discussions with local equipment dealers and with Dr. Howard Doster, Dr. Harry Galloway and Dr. Donald Griffith at Purdue University provided information for making the modifications.

There are many variations available to the farmer for each item listed in Table A-2. Here, an attempt was made to insure that the equipment specified was appropriate for the soil conditions, reflected current farming practices for a well managed farm, including recent technology changes and was appropriately sized so that, for example, the plow was not oversized compared to the tractor.

Current list prices for the farm machines were calculated, for the most part, by averaging local equipment dealers estimates. As a check, current Ames, Iowa prices were also obtained as well as a national USDA price index which was used to update the prices in Appendix C, Control of Water Pollution from Cropland.

Other items in Table A-2 were calculated as indicated in the footnotes using data from Appendix C, Control of Water Pollution from Cropland, and from the Purdue Crop Budget.

Table A-2. Machinery Fixed Costs

Machine	Size & Other Specs.	Initial List Price ($)*	Salvage** Value (%)	Economic** Life	Yearly Depreciation (straight line method)	Taxes, Insurance*** and Housing	Interest+	Yearly Fixed Cost
Stalk Shredder	12' flail	3,050	13.7	12	219.35	137.25	138.71	495.31
Moldboard Plow	5-16"; high clearance; sheer bolt	4,000	17.7	10	329.20	180.00	188.32	697.52
Chisel Plow	10'; three bar; straight shank; pull type	2,150	13.7	12	154.62	96.75	97.78	349.15
Disk	20'; tandem; hydraulic	6,750	17.7	10	555.53	303.75	317.79	1,177.07
Harrow	20'; hydraulic mounted	750	17.7	12	51.44	33.75	35.31	120.50
Sprayer	tractor mounted (rear); 120" boom size	1,400	17.7	10	115.22	63.00	65.91	244.13
Planter	4-30"; conventional; no fertilizer attachments	4,000	17.7	10	329.20	180.00	188.32	697.52
No-till Planter	4-30"; fluted coulters; no fertilizer attachments	5,500	17.7	10	452.65	247.50	258.94	959.09
Wheat Drill	12'; with grass seeding attachments	4,250	9.7	14	274.13	191.25	186.49	651.87
Cultivator	4-30"; rear mount	2,000	17.7	10	164.60	90.00	94.16	348.76
Combine	Small (70-80 hp); self-propelled; diesel	27,100	18.9	10	2,197.81	1,219.50	1,288.88	4,706.19
Platform	13'; hydraulic; with cutter bar	3,850	18.9	10	312.24	173.25	183.11	668.60
Corn Head	4-30"; picker-sheller	7,800	18.9	10	632.58	351.00	370.97	1,354.55
Hay Mower/ Conditioner	7'	4,800	12.5	12	350.00	216.00	216.00	782.00
Hay Rake	Side delivery	1,250	12.5	12	91.15	56.25	56.25	203.65
Hay Baler	PTO; 50-60 lb bales; rectangle bales; twine	5,100	21.1	8	502.99	229.50	247.04	979.53

* Prices are averages of local Indiana equipment dealer 1977 estimates except for no-till planter price which is from the Department of Agricultural Economics, Iowa State University for 1977.

** Table 2 Appendix C, Control of Water Pollution from Cropland, Vol. II, U.S. Government Printing Office, Washington, D.C., 1976.

*** Taxes two percent, insurance one and a half percent of initial cost, Purdue Crop Budget, p. 22; housing one percent, Appendix C, Table 2.

+ Eight percent per year, Purdue Crop Budget, Department of Agricultural Economics, Purdue University, Lafayette, Indiana, 1977, p. 22. [(I+S)/2] r = yearly cost.

Table A-3. Machinery Costs

Data from Table 3, Appendix C, Control of Water Pollution from Cropland, Vol. II, were used as the basis for this table. The eight farm practices considered were developed from those listed in Appendix C, Control of Water Pollution from Cropland, Vol. II, with modifications so that they represented some of the tillage practices and crop rotations used in the tillage trials in the EPA Black Creek demonstration project. Dr. Daniel McCain, Allen County Soil Conservation District, and Mr. James Morrison and Dr. Donald Griffith of Purdue University provided guidance for the selection of the practices described in Table A-3.

The practices were chosen to reflect the effects of changes in tillage methods and changes in rotation of crops. Continuous corn and a corn-soybean rotation are each subjected to three farming practices, conventional tillage, reduced tillage, and no tillage. A more extensive rotation consisting of corn, soybean, wheat, meadow is also included, subject to two tillage practices, one in which the meadow is plowed conventionally before the corn is planted and the other in which the meadow is treated with herbicide and the corn planted directly in the remaining sod.

Tables A-4 through A-12 show eleven farming practices. These include the eight from Table A-3 plus three from Table A-3 with terracing added: continuous corn, conventional tillage; continuous corn, chisel tillage; corn-bean rotation, no-till planting.

Hours per acre data were taken from Appendix C, Control of Water Pollution from Cropland, Vol. II, and reviewed with Black Creek project personnel. Equipment specification changes made some updated figures necessary; sources for updated figures are noted on the table. Most implements are used only once over the field except for disking for chisel plow and hay harvesting equipment. For these implements the times over is variable and the number shown is the average. Total hours is equal to the product of hours/acre, acres of use and times over. Repair costs per 100 hours for the harrow were calculated from Appendix C (Control of Water Pollution from Cropland, Vol II) data to be three percent and for the hay mower/conditioner, seven percent.

Table A-3. Machinery Costs

Implement	Hours/ Acre[a]	Acres of use[b]	Times Over[c]	Total hours	Repair Cost/ 100 hrs, $[d]	Total Repair Cost, $	Yearly Fixed Cost, $	Total Cost, $
Corn, fall turn-plow, conventional								
moldboard plow[e]	.36	250	1	90	200.00	180.00	697.52	877.52
disk	.10	250	1	25	337.50	84.38	1177.07	1261.45
harrow	.10	250	1	25	22.50	5.63	120.50	126.13
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
planter	.17[f]	250	1	42.50	320.00	136.00	697.52	815.52
cultivator	.21	250	1	52.50	100.00	52.50	348.76	401.26
combine	.47[g]	250	1	117.50	542.00	636.85	4706.19	5343.04
corn head	.47[g]	250	1	117.50	156.00	183.30	1354.55	1537.85
Total								10,643.65
Corn, fall shred stalks, chisel plow, spring disk								
stalk shredder	.18	250	1	45	122.00	54.90	495.31	550.21
chisel plow	.21[h]	250	1	52.50	107.50	56.44	349.15	405.59
disk	.10	250	1.5	37.50	337.50	126.56	1177.07	1303.63
harrow	.10	250	1.5	37.50	22.50	8.44	120.50	128.94
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
planter	.17[f]	250	1	42.50	320.00	136.00	697.52	815.52
combine	.47[g]	250	1	117.50	542.00	636.85	4706.19	5343.04
corn head	.47[g]	250	1	117.50	156.00	183.30	1354.55	1537.85
Total								10,365.66
Corn, fall shred, no -till plant								
stalk shredder	.18	250	1	45	122.00	54.90	495.31	550.21
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
no-till planter	.22	250	1	55	440.00	242.00	959.09	1201.09
combine	.47[g]	250	1	117.50	542.00	636.85	4706.19	5343.04
corn head	.47[g]	250	1	117.50	156.00	183.30	1354.55	1537.85
Total								8,913.07

Notes (see following pages)

Table A-3 (continued)

Implement	Hours/ Acre^a	Acres of use^b	Times Over^c	Total hours	Repair Cost/ 100 hrs, \$^{d}	Total Repair Cost, \$	Yearly Fixed Cost, \$	Total Cost, \$
Corn-soybeans, fall turn-plow, conventional								
moldboard plow	.36	250	1	90	200.00	180.00	697.52	877.52
disk	.10	250	1	25	337.50	84.38	1177.07	1261.45
harrow	.10	250	1	25	22.50	5.63	120.50	126.13
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
planter	.17^f	250	1	42.50	320.00	136.00	697.52	815.52
cultivator	.21	250	1	52.50	100.00	52.50	348.76	401.26
combine corn	.479^g	125	1	96.25	542.00	521.68	4706.19	5227.87
combine soybeans	.30	125	1					
corn head	.479^g	125	1	58.75	156.00	91.65	1354.55	1446.20
platform	.30	125	1	37.50	77.00	28.88	668.60	697.48
Total								11,134.31
Corn-soybeans, fall shred, chisel plow, spring disk								
stalk shredder	.18	125	1	22.50	122.00	27.45	495.31	522.76
chisel plow	.21^h	250	1	52.50	107.50	56.44	349.15	405.59
disk	.10	250	1.5	37.50	337.50	126.56	1177.07	1303.63
harrow	.10	250	1.5	37.50	22.50	8.44	120.50	128.94
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
planter	.17^f	250	1	42.50	320.00	136.00	697.52	815.52
combine corn	.479^g	125	1	96.25	542.00	521.68	4706.19	5227.87
combine soybeans	.30	125	1					
corn head	.479^g	125	1	58.75	156.00	91.65	1354.55	1446.20
platform	.30	125	1	37.50	77.00	28.88	668.60	697.48
Total								10,828.87
Corn-soybeans, fall shred, no-till plant								
stalk shredder	.18	125	1	22.50	122.00	27.45	495.31	522.76
sprayer	.21	250	1	52.50	70.00	36.75	244.13	280.88
no-till planter	.22	250	1	.55.00	440.00	242.00	959.09	1201.09

Notes (see following pages)

Table A-3 (continued)

Implement	Hours/ Acre[a]	Acres of use[b]	Times Over[c]	Total hours	Repair Cost/ 100 hrs, $[d]	Total Repair Cost, $	Yearly Fixed Cost, $	Total Cost, $
Corn-soybeans, fall shred, no-till plant (continued)								
combine corn	.47[g]	125	1	96.25	542.00	521.68	4706.19	5227.87
combine soybeans	.30	125	1					
corn head	.47[g]	125	1	58.75	156.00	91.65	1354.55	1446.20
platform	.30	125	1	37.50	77.00	28.88	668.60	697.48
Total								9,376.28
Corn-soybeans-wheat-meadow, fall turn-plow corn, fall shred, no-till plant others								
stalk shredder	.18	62.5	1	11.25	122.00	13.73	495.31	509.04
moldboard plow	.36	62.5	1	22.50	200.00	45.00	697.52	742.52
disk	.10	125	1	12.50	337.50	42.19	1177.07	1219.26
harrow	.10	125	1	12.50	22.50	2.81	120.50	123.31
sprayer	.21	125	1	26.25	70.00	18.38	244.13	262.51
no-till planter	.22	125	1	27.50	440.00	121.00	959.09	1080.09
wheat drill	.25	62.5	1	15.63	340.00	52.22	651.87	704.09
combine corn	.47[g]	62.5	1	66.88	542.00	362.49	4706.19	5068.68
combine soybeans	.30	62.5	1					
combine wheat	.30	62.5	1					
corn head	.47[g]	62.5	1	29.38	156.00	45.83	1354.55	1400.38
platform	.30	125	1	37.50	77.00	28.88	668.60	697.48
hay mower/conditioner	.34[g]	62.5	3.5	74.38	336.00	249.92	782.00	1031.92
hay rake	.30	62.5	3.5	65.63	75.00	49.22	203.65	252.87
hay baler	.63	62.5	3.5	137.81	306.00	421.70	979.53	1401.23
Total								14,493.38
Corn-soybeans-wheat-meadow, fall shred, no-till plant								
stalk shredder	.18	62.5	1	11.25	122.00	13.73	495.31	509.04
disk	.10	62.5	1	6.25	337.50	21.09	1177.07	1198.16
harrow	.10	62.5	1	6.25	22.50	1.41	120.50	121.91
sprayer	.21	125	1	26.25	70.00	18.38	244.13	262.51
no-till planter	.22	125	1	27.50	440.00	121.00	959.09	1080.09
wheat drill	.25	62.5	1	15.63	340.00	52.22	651.87	704.09

Notes (see following page)

Table A-3 (continued)

Implement	Hours/ Acre[a]	Acres of use[b]	Times Over[c]	Total hours	Repair Cost/ 100 hrs, $[d]	Total Repair Cost, $	Yearly Fixed Cost, $	Total Cost, $
Corn-soybeans-wheat-meadow, fall shred, no-till plant (continued)								
combine corn	.47[g]	62.5	1					
combine soybeans	.30	62.5	1	66.88	542.00	362.49	4706.19	5068.68
combine wheat	.30	62.5	1					
corn head	.47[g]	62.5	1	29.38	156.00	45.83	1354.55	1400.38
platform	.30	125	1	37.50	77.00	28.88	668.60	697.48
hay mower/conditioner	.34[g]	62.5	3.5	74.38	336.00	249.92	782.00	1031.92
hay rake	.30	62.5	3.5	65.63	75.00	49.22	203.65	252.87
hay baler	.63	62.5	3.5	137.81	306.00	421.70	979.53	1401.23
Total								13,728.36

Notes:

a. Source: Table 3, Appendix C, Control of Water Pollution from Cropland, unless otherwise noted.

b. Acres on which implement is used each year.

c. Number of trips through field with implement.

d. Computed as percentage of list price. Used two percent for combine, platform, corn head; three percent for harrow; four percent for stalk shredder; five percent for moldboard plow, chisel plow, cultivator, sprayer, disk; six percent for hay rake, hay baler; seven percent for hay mower/conditioner; eight percent for planters, wheat drill. Source: Table 3, Appendix C.

e. See Table A-2 for equipment specifications.

f. Dr. Klaus Alt, ISU, Ames, Iowa.

g. Midwest Farm Planning Manual, p. 142.

h. Purdue Crop Budget, p. 30.

Table A-4. Tractor Costs

Tractor hours per acre were calculated by summing the hours per acre given in Table A-3 for each machine pulled by a tractor for each practice considered. The disk and harrow were assumed to move over the field in tandem for all alternatives where they are used, and to average 1.5 times over the field annually for the C-B chisel plow option. Additional times over the field were also counted for the haying operations such that each time an operation is carried out (i.e. mowing, raking, baling) tractor usage is increased. The corn head and platform are attachments to the combine and so their hours per acre were not included. For the rotation options, hours per acre figures were adjusted for some implements prior to summing, to reflect the fact that they are crop-specific and not used in all years of the rotation (the "acres of use" column, Table A-3, accounts for this adjustment factor).

Of the 0.2 hours per acre added for fertilizer application, 0.1 is for N and 0.1 for P and K application. For the corn-bean rotation, fertilizer is only applied once every two years so only 0.1 hours per acre were added. For the CBWM option, 0.125 hours per acre were added because N, P, K are applied once for corn and beans and once for wheat and K is applied once for the meadow.

Other calculations were completed as indicated in the footnotes. List prices are averages of local dealer estimates. Economic life was estimated using information from the Midwest Farm Planning Manual based on the total annual tractor hours for each option.

Table A-4. Tractor Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Tractor hours per acre[a]	1.72	1.59	1.28	1.54	1.32	1.01	1.97	1.85	1.72	1.59	1.01
Total tractor hours[b]	473.00	437.25	352.00	347.27	363.00	277.75	541.75	508.75	473.00	437.25	277.75
Tractor initial costs, $[c]	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00	23,600.00
Economic life, years[d]	12	12	13	13	13	14	12	12	12	12	14
Salvage value, percent[e]	25.5	25.5	23.5	23.5	23.5	21.5	25.5	25.5	25.5	25.5	21.5
Yearly depreciation, $	1,465.17	1,465.17	1,388.77	1,388.77	1,388.77	1,323.29	1,465.17	1,465.17	1,465.17	1,465.17	1,323.29
Taxes, insurance & housing, $[f]	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00	1,062.00
Average annual interest, $[g]	1,184.72	1,184.72	1,165.84	1,165.84	1,165.84	1,146.96	1,184.72	1,184.72	1,184.72	1,184.72	1,146.96
Total fixed costs, $	3,711.89	3,711.89	3,616.61	3,616.61	3,616.61	3,532.25	3,711.89	3,711.89	3,711.89	3,711.89	3,532.25
Repair costs, $[h]	893.02	825.53	664.58	655.65	685.34	524.39	1,022.82	960.52	893.02	825.53	524.39
Total tractor costs, $ (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Assume tractor is required for harvest hauling in amount equivalent to time requirements for combine. Add 0.2 hours for application of fertilizer with rented implements.

b. Increased by 10 percent for idling, travel to field, etc.

c. 100 PTO hp diesel (average of local Indiana equipment dealer price estimates).

d. From Sidney James (ed.) Midwest Farm Planning Manual, 3rd edition, Revised Printing, ISU Press, Ames, Iowa, 1975, Table 4.7, p. 129.

e. From Appendix C, Table 4, used values corresponding to appropriate economic life.

f. Taxes 2%, insurance 1.5% of initial cost, Purdue Crop Budget, p.22; housing 1%, Appendix C, Table 2.

g. 8% per year, Purdue Crop Budget, p. 22; yearly cost =[(I+S)/2]r.

h. 0.8% of list price per 100 hours of use, Appendix C, p. 182.

Table A-5. Fuel Costs

Fuel costs were based on cost per hour for total tractor and combine hours. Tractor fuel costs were estimated according to a standard formula, 0.044 times the maximum PTO hp. Combine fuel costs were more complicated to estimate since data on fuel consumption are only available on a per acre basis and vary according to the crop being harvested. The formula used was gal./acre x 1/(hours per acre) x $0.50/gal. x 1.15 (for lubrication costs). For the corn-soybean rotations and the corn-soybean-wheat-meadow rotations the results using the above formula for each crop were averaged.

Table A-5. Fuel Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Total tractor hours	473.00	437.25	352.00	347.27	363.00	277.75	541.75	508.75	473.00	437.25	277.75
Fuel cost per tractor hour, $[a]	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53	2.53
Tractor fuel cost, $	1,196.69	1,106.24	890.56	878.59	918.39	702.71	1,370.63	1,287.14	1,196.69	1,106.24	702.71
Total combine hours	117.50	117.50	117.50	96.25	96.25	96.25	66.88	66.88	117.50	117.50	96.25
Fuel cost per combine hour, $[b]	1.96	1.96	1.96	2.03	2.03	2.03	2.06	2.06	1.96	1.96	2.03
Combine fuel cost, $	230.30	230.30	230.30	195.39	195.39	195.39	137.77	137.77	230.30	230.30	195.39
Total fuel cost, $	1,426.99	1,336.54	1,120.86	1,073.97	1,113.78	898.10	1,508.40	1,424.91	1,426.99	1,336.54	898.10

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Fuel consumption (diesel) gallons per hour = 0.044 x PTO hp. Lubrication costs at 15% of fuel cost, George E. Ayres, Estimating Farm Machinery Costs, ISU Cooperative Extension Service, Ames, Iowa, November 1976, p. 8. Assume diesel fuel at $0.50/gal., Purdue Crop Budget, p. 24.

b. Fuel consumption (diesel) corn = 1.60 gal./acre; beans, wheat = 1.10 gal./acre, George E. Ayres, Fuel Required for Field Operations, ISU Cooperative Extension Service, Ames, Iowa, May 1976, p. 2. Lubrication at 15% of fuel cost. Assume diesel fuel at $0.50/gal., Purdue Crop Budget, p. 24.

Table A-6. Seed Costs

Seed costs are calculated from the estimated amounts of seed applied per acre and the price of seed per pound or bushel. Seeding rates for corn vary according to soil type and tillage practice. Wheat and hay seed amounts are constant for the two tillage practices involving them. Soybean seed amounts are increased for reduced tillage, but are insensitive to soil type.

Seed cost per acre is calculated as the average for all years of the rotation, if not continuous corn. Total seed cost is determined for the whole farm based upon the average annual seed cost and the total acres farmed.

Table A-6. Seed Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn											
Seeding rate (seeds/acre)[a]											
A uplands	20,000	20,000	21,000	20,000	20,000	21,000	20,000	21,000	20,000	20,000	21,000
B ridge	22,000	22,000	23,000	22,000	22,000	23,000	22,000	23,000	22,000	22,000	23,000
C lowlands	24,000	24,000	25,000	24,000	24,000	25,000	24,000	25,000	24,000	24,000	25,000
Seed amount, bu.[b]/acre											
A uplands	.238	.238	.250	.238	.238	.250	.238	.250	.238	.238	.250
B ridge	.262	.262	.274	.262	.262	.274	.262	.274	.262	.262	.274
C lowlands	.286	.286	.298	.286	.286	.298	.286	.298	.286	.286	.298
Seed cost, $[c]/acre											
A uplands	9.52	9.52	10.00	9.52	9.52	10.00	9.52	10.00	9.52	9.52	10.00
B ridge	10.48	10.48	10.96	10.48	10.48	10.96	10.48	10.96	10.48	10.48	10.96
C lowlands	11.44	11.44	11.92	11.44	11.44	11.92	11.44	11.92	11.44	11.44	11.92
Wheat											
Seed amount, bu.[d]/acre							1.5	1.5			
Seed cost, $[e]/acre							7.13	7.13			
Hay											
Seed amount, lbs.[f]/acre							14.00	14.00			
Seed cost, $[g]/acre							18.12	18.12			
Soybeans											
Seed amount, bu.[h]/acre				1.00	1.00	1.05	1.05	1.05			1.05
Seed cost, $[i]/acre				10.80	10.80	11.34	11.34	11.34			11.34
Seed cost per acre, $[j]											
A uplands	9.52	9.52	10.00	10.16	10.16	10.67	11.53	11.65	9.52	9.52	10.67
B ridge	10.48	10.48	10.96	10.64	10.64	11.15	11.77	11.89	10.48	10.48	11.15
C lowlands	11.44	11.44	11.92	11.12	11.12	11.63	12.01	12.13	11.44	11.44	11.63

Notes (see following page)

Table A-6 (continued)

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Total seed cost, $											
A upland	2,380.00	2,380.00	2,500.00	2,540.00	2,540.00	2,667.50	2,882.50	2,912.50	2,380.00	2,380.00	2,667.50
B ridge	2,620.00	2,620.00	2,740.00	2,660.00	2,660.00	2,782.50	2,942.50	2,972.50	2,620.00	2,620.00	2,782.50
C lowlands	2,860.00	2,860.00	2,980.00	2,780.00	2,780.00	2,907.50	3,002.50	3,032.50	2,860.00	2,860.00	2,907.50

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Based on discussions with Dr. Donald Griffith, Purdue University; Rex Journey, Allen County Soil Conservation District.

b. Based on 84,000 seeds per bushel, Appendix C, Table 6.

c. Assume price of $40 per bushel, Adler's Seed, Kokomo, Indiana.

d. Based on discussions with Dr. Harry Galloway, Purdue University.

e. Assume price of $4.75 per bushel, Adler's Seed, Kokomo, Indiana.

f. Assume 4 lbs. alfalfa, 6 lbs. orchard grass, 4 lbs. red clover from discussion with Dr. Harry Galloway, Purdue University.

g. Assume prices for orchard grass @ $0.72 per lb.; alfalfa @ $2.10 per lb.; red clover @ $1.35 per lb., Indiana Farm Bureau, Indianapolis.

h. Based on discussions with Dr. Harry Galloway, Dr. Donald Griffith, Purdue University.

i. Assume price of $10.80 per bu., Indiana Farm Bureau, Indianapolis.

j. Average annual seed cost.

Table A-7. Fertilizer Costs

Fertilizer costs are calculated from the estimated pounds per acre application of N, P_2O_5 and K_2O for corn, soybeans, wheat and hay, and the price per pound of these fertilizers. Fertilizer application rates for corn vary according to soil type and tillage practice. Application rates are based upon discussions with the individuals indicated in the footnotes and represent normal expected application rates for the Black Creek area. Lower yields are expected on the poorer upland soils and also less N fertilizer is normally applied. However, more P_2O_5 is applied there. Ten percent more N is used for all no-till alternatives. P_2O_5 applications for wheat and soybeans on the uplands are increased in the same proportion as for corn. Wheat yields are not expected to vary according to location (soil type) or tillage practice and, therefore, N application for wheat is constant. Since this is assumed to be a well-managed farm, K_2O is applied to the hay as well as the other crops. Soybeans in the corn-bean rotation are expected to contribute 10 pounds of N per acre to the corn. Legumes in the corn-bean-wheat-meadow rotation are expected to contribute 50 pounds of N per acre. These fertilizer application rates are appropriate for the Black Creek area.

For the rotations, average annual fertilizer amounts are calculated and the prices applied to these figures. Total fertilizer cost is determined for the whole farm based upon these annual costs. Total fertilizer costs include the rental of application equipment. For calculating equipment rental costs it is assumed that the P and K for the soybeans are applied along with the corn fertilizer in the corn year for corn-soybean rotation alternatives and also that N is not applied to hay for corn-soybean-wheat-hay alternatives, so equipment costs are correspondingly reduced.

Table A-7. Fertilizer Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn											
N^a, lbs/acre											
A uplands	125	125	137.5^d	115^b	115^b	126.5^d	75^c	82.5^d	125	125	126.5^d
B ridge	160	160	176	150	150	165	110	121	160	160	165
C lowlands	160	160	176	150	150	165	110	121	160	160	165
P_2O_5, lbs/acre											
A uplands	44	44	44	44	44	44	44	44	44	44	44
B ridge	40	40	40	40	40	40	40	40	40	40	40
C lowlands	40	40	40	40	40	40	40	40	40	40	40
K_2O, lbs/acre	50	50	50	50	50	50	50	50	50	50	50
Hay											
K_2O, lbs/acre							120	120			
Wheat											
N, lbs/acre							60	60			
P_2O_5, lbs/acre											
A uplands							44	44			
B ridge							40	40			
C lowlands							40	40			
K_2O, lbs/acre							40	40			

Table A-7 (continued)

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Soybeans											
P_2O_5, lbs/acre											
A uplands				11	11	11	11	11			11
B ridge				10	10	10	10	10			10
C lowlands				10	10	10	10	10			10
K_2O, lbs/acre				70	70	70	70	70			70
Average Annual amount, lbs/acre											
N											
A uplands	125	125	137.5	57.5	57.5	63.25	33.75	35.63	125	125	63.25
B ridge	160	160	176	75	75	82.5	42.5	45.25	160	160	82.5
C lowlands	160	160	176	75	75	82.5	42.5	45.25	160	160	82.5
P_2O_5											
A uplands	44	44	44	27.5	27.5	27.5	24.75	24.75	44	44	27.5
B ridge	40	40	40	25	25	25	22.5	22.5	40	40	25
C lowlands	40	40	40	25	25	25	22.5	22.5	40	40	25
K_2O	50	50	50	60	60	60	70	70	50	50	60
Cost of fertilizer per acre, \$*											
A uplands	29.11	29.11	30.74	18.11	18.11	18.85	15.39	15.63	29.11	29.11	18.85
B ridge	32.90	32.90	34.98	19.90	19.90	20.88	16.11	16.46	32.90	32.90	20.88
C lowlands	32.90	32.90	34.98	19.90	19.90	20.88	16.11	16.46	32.90	32.90	20.88

Table A-7 (continued)

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Total cost of fertilizer, $											
A uplands	7277.50	7277.50	7685.00	4527.50	4527.50	4712.50	3847.50	3907.50	7277.50	7277.50	4712.50
B ridge	8225.00	8225.00	8745.00	4975.00	4975.00	5220.00	4027.50	4115.00	8225.00	8225.00	5220.00
C lowlands	8225.00	8225.00	8745.00	4975.00	4975.00	5220.00	4027.50	4115.00	8225.00	8225.00	5220.00
Rental of application equipment, $[f]	262.50	262.50	262.50	131.25	131.25	131.25	153.13	153.13	262.50	262.50	131.25
Total fertilizer costs, $											
A uplands	7540.00	7540.00	7947.50	4658.75	4658.75	4843.75	4000.63	4060.63	7540.00	7540.00	4843.75
B ridge	8487.50	8487.50	9007.50	5106.25	5106.25	5351.25	4180.63	4268.13	8487.50	8487.50	5351.25
C lowlands	8487.50	8487.50	9007.50	5106.25	5106.25	5351.25	4180.63	4268.13	8487.50	8487.50	5351.25

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Fertilizer amounts based on discussions with Dr. Harry Galloway, Dr. Donald Griffith, Purdue University and Rex Journey, Allen County Soil Conservation District.

b. **Assumes** 10 lb credit from soybeans to corn, from discussions with Dr. Harry Galloway, Purdue University.

c. **Assumes** 50 lb credit from legumes to corn, from discussions with Dr. Harry Galloway, Purdue University.

d. Assume 10 percent increase in N application for all no-tillage alternatives, from discussions with Dr. Harry Galloway, Purdue University.

e. Assume N as NH_3. Prices per lb are $0.13 for N, $0.19 for P_2O_5, and $0.09 for K_2O, Purdue Crop Budget.

f. Assume $0.70/acre for NH_3 knife and $0.35/acre for 4-ton bulk spreader, Appendix C, Table 7 figures updated using USDA equipment price index from 1974 to 1976 of 1.415.

Table A-8. Pesticide Costs

Pesticide costs were calculated based on recommended applications of appropriate herbicides and insecticides for the soil types, tillage practices and rotations considered. The following factors were accounted for:

- No tillage options require more herbicides because no cultivation is used to destroy weeds.
- The corn-bean-wheat-meadow alternative in which the corn is planted directly into the sod requires an additional type of herbicide to kill the remaining hay.
- A different herbicide combination is used for corn than soybeans.
- The corn-soybean rotation is assumed to prevent a corn rootworm problem but increases the likelihood of a cutworm problem.
- Cutworm has a higher probability in no tillage options due to the amount of residue remaining.
- Wireworm may be a problem where meadow is part of a rotation.
- Insecticides are not generally applied to soybeans.

For all the options considered, a risk averse farmer is assumed, who applies pesticides when there is a likelihood that they will be needed. In actuality, the use of the insecticides, particularly, will vary from farm to farm depending on local conditions.

Using current prices, cost per acre for each crop was calculated and then multiplied by the number of acres which would be in that crop in the rotation. Total cost is the sum of the costs for each crop.

Table A-8. Pesticide Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn, Amounts											
Herbicide[a] (Lasso-Atrex comb.), qt											
A uplands	3.50	3.50	4.67	3.50	3.50	4.08	3.50	3.50	3.50	3.50	4.08
B ridge	3.00	3.00	4.00	3.00	3.00	3.50	3.00	3.00	3.00	3.00	3.50
C lowlands	4.00	4.00	5.33	4.00	4.00	4.67	4.00	4.00	4.00	4.00	4.67
Herbicide (Paraqat), qt			1.00			1.00		1.00			1.00
Herbicide (2-4-D), pt								1.00			
Insecticide[b]											
(furadan), lb active	1.33	1.33	1.33						1.33	1.33	
(counter), lb active							1.33	1.33			
(lorsban), lb form.			8.87	8.87	8.87	8.87	8.87	8.87			8.87
Soybeans, Amounts											
Herbicide (Lasso)qt											
A uplands				1.75	1.75	2.04	2.04	2.04			2.04
B ridge				1.50	1.50	1.75	1.75	1.75			1.75
C lowlands				2.00	2.00	2.33	2.33	2.33			2.33
Herbicide (Sencor) lb											
A uplands				.38	.38	.38	.38	.38			.38
B ridge				.25	.25	.25	.25	.25			.25
C lowlands				.50	.50	.50	.50	.50			.50
Corn, Cost											
Herbicide, $/acre[c]											
A uplands	13.51	13.51	26.78	13.51	13.51	24.50	13.51	23.76	13.51	13.51	24.50
B ridge	11.59	11.59	24.19	11.59	11.59	22.26	11.59	21.84	11.59	11.59	22.26
C lowlands	15.44	15.44	29.36	15.44	15.44	26.78	15.44	25.69	15.44	15.44	26.78

Table A-8. (Continued)

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn, Cost (continued)											
Insecticide, $/acre[d]	9.31	9.31	18.36	9.05	9.05	9.05	17.14	17.14	9.31	9.31	9.05
Acres	250	250	250	125	125	125	62.5	62.5	250	250	125
Total cost, $											
A uplands	5705.00	5705.00	11,285.00	2820.00	2820.00	4193.75	1915.63	2556.25	5705.00	5705.00	4193.75
B ridge	5225.00	5225.00	10,637.50	2580.00	2580.00	3913.75	1795.63	2436.25	5225.00	5225.00	3913.75
C lowlands	6187.50	6187.50	11,930.00	3061.25	3061.25	4478.75	2036.25	2676.88	6187.50	6187.50	4478.75
Soybeans, Cost											
Herbicide, $/acre[c]											
A uplands				13.76	13.76	14.95	14.95	14.95			14.95
B ridge				10.46	10.46	11.49	11.49	11.49			11.49
C lowlands				16.90	16.90	18.24	18.24	18.24			18.24
Acres				125	125	125	62.5	62.5			125
Total cost, $											
A uplands				1720.00	1720.00	1868.75	934.38	934.38			1868.75
B ridge				1307.50	1307.50	1436.25	718.13	718.13			1436.25
C lowlands				2112.50	2112.50	2280.00	1140.00	1140.00			2280.00
Total Pesticide Costs, $											
A uplands	5705.00	5705.00	11,285.00	4540.00	4540.00	6062.50	2850.01	3490.63	5705.00	5705.00	6062.50
B ridge	5225.00	5225.00	10,637.50	3887.50	3887.50	5350.00	2513.76	3154.38	5225.00	5225.00	5350.00
C lowlands	6187.50	6187.50	11,930.00	5173.75	5173.75	6758.75	3176.25	3816.88	6187.50	6187.50	6758.75

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Herbicide types and application rates based on discussions with Dr. James Williams, Purdue University.

b. Insecticide types and application rates based on discussions with Dr. Thomas Turpin, Purdue University and Dr. David Pimental, Cornell University. For the base case alternative it was assumed that all insecticide possibly necessary is applied to each acre. This assumption results in an upper bound for chemical costs. Treatment for observed damage and associated costs are included in Alternative E, Insecticide Scouting.

c. Lasso$4.05/lb active, Atrex $3.67/qt, Paraquat $8.75/qt, 2-4-D ester $1.50/pt, Indianapolis Farm Bureau prices, Spring, 1977.

d. Furadan $7/lb active, Counter $6.08/bl active, Indianapolis Farm Bureau; Lorsban $1.02/lb, Dow Chemical Co., Indianapolis, Indiana.

e. Lasso $4.05/qt, Sencor $17.60.lb, Indianapolis Farm Bureau.

Table A-9. Labor Costs

Labor costs are calculated from direct labor hours plus overhead and hourly labor wage rates. The direct labor hours are the sum of total tractor hours plus total combine hours. The overhead rate covers general farm overhead costs in addition to labor overhead. An average farm wage rate for Indiana was used.

Table A-9. Labor Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Total direct labor, hours[a]	590.50	554.75	469.50	464.77	459.25	374.00	608.63	575.63	590.50	554.75	374.00
Overhead (30%), hours	177.15	166.43	140.85	139.43	137.78	112.20	182.59	172.69	177.15	166.43	112.20
Total labor, hours	767.65	721.18	610.35	604.20	597.03	486.20	791.22	748.32	767.65	721.18	486.20
Cost per hour, $[b]	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Total labor costs, $	2149.42	2019.30	1708.98	1691.76	1671.68	1361.36	2215.42	2095.30	2149.42	2019.30	1361.36

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Tractor hours plus combine hours.

b. Indiana Crop and Livestock Statistics, Purdue University Agricultural Experiment Station, August 1977, Table 89, "Farm Wage Rates," used average of Field and Livestock Workers and Machine Operators.

Table A-10. Other Costs

Corn drying costs were estimated from the expected crop yield and the costs of elevator drying. It was assumed that all the corn harvested would require an average of ten points of moisture removed. It was assumed that soybeans did not require drying.

Interest on operating capital was calculated for each item of expense based on an annual interest rate of 8-1/2 percent. Except for fertilizer and labor costs the interest was charged for the period indicated on the table for each item.

Fertilizer costs were divided into nitrogen costs which were assumed to be carried for about twelve months and phosphorous and potash costs which were carried approximately eight months. The actual calculation was done as follows: Fertilizer costs x 8/12 x .085 x 1.35 (factor to account for differences in capital carrying time) - Fertilizer cost - .0765 = Interest on Operating Capital for Fertilizer.

Interest on operating capital for labor is based on a variable labor force over the year; for example, additional labor required during harvesting is not included in the interest calculation. The calculation was carried out as follows: (Tractor hours - harvest hours) x 2.80 x 3/12 x .085 x 1.46 (adjustment factor) = Interest on Operating Capital for Labor.

Total other costs are the sum of drying costs and interest costs.

Table A-10. Other Costs

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn Drying											
Grain harvested, bu.											
A uplands	26,250	26,250	24,937.50	13,781.25	13,781.25	13,781.25	7,218.75	7,218.75	28,000	28,000	14,656.25
B ridge	32,500	32,500	32,500	17.062.50	17,062.50	17,062.50	8,937.50	8,937.50	34,250	34,250	17,937.50
C lowlands	32,500	32,500	26,000	17,062.50	17,062.50	15,356.25	8,937.50	8,490.63	34,250	34,250	16,231.25
Cost per bu., $[a]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Total cost											
A uplands	4,200	4,200	3,990	2,205	2,205	2,205	1,155	1,155	4,480	4,480	2,345
B ridge	5,200	5,200	5,200	2,730	2,730	2,730	1,430	1,430	5,480	5,480	2,870
C lowlands	5,200	5,200	4,160	2,730	2,730	2,457	1,430	1,358.50	5,480	5,480	2,597
Interest on Operating Capital[b]											
Fertilizer (8 mo.)											
A uplands	576.81	576.81	607.98	356.39	356.39	370.55	306.05	310.64	576.81	576.81	370.55
B ridge	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
C lowlands	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
Seed (8 mo.)											
A uplands	134.87	134.87	141.67	143.93	143.93	151.16	163.34	160.22	134.87	134.87	151.16
B ridge	148.47	148.47	155.27	150.73	150.73	157.96	166.74	163.62	148.47	148.47	157.96
C lowlands	162.07	162.07	168.87	157.53	157.53	164.76	170.14	167.02	162.07	162.07	164.76
Pesticide (6 mo.)											
A uplands	242.46	242.46	479.61	192.95	192.95	257.66	121.13	148.35	242.46	242.46	257.66
B ridge	222.06	222.06	452.09	165.22	165.22	227.38	106.83	134.06	222.06	222.06	227.38
C lowlands	262.97	262.97	507.03	219.88	219.88	287.25	134.99	162.22	262.97	262.97	287.25
Fuel (3 mo.)	30.32	28.40	23.82	22.82	23.67	19.08	32.05	30.28	30.32	28.40	19.08
Labor (3 mo.)	30.88	27.78	20.37	21.81	23.17	15.77	17.12	14.25	30.88	27.78	15.77
Total Interest											
A uplands	1,015.34	1,010.32	1,273.45	737.90	740.11	814.22	639.69	663.74	1,015.34	1,010.32	814.22
B ridge	1,081.02	1,076.00	1,340.62	751.21	753.42	829.56	642.56	668.72	1,081.02	1,076.00	829.56
C lowlands	1,136.53	1,131.51	1,409.16	812.67	814.88	896.23	674.12	700.28	1,136.53	1,131.51	896.23
Total Other Costs											
A uplands	5,215.34	5,210.32	5,263.45	2,942.90	2,945.11	3,019.22	1,794.69	1,818.74	5,495.34	5,490.32	3,159.22
B ridge	6,281.02	6,276.00	6,540.62	3,481.21	3,483.42	3,559.56	2,072.56	2,098.72	6,561.02	6,556.00	3,699.56
C lowlands	6,336.53	6,331.51	5,569.16	3,542.67	3,544.88	3,353.23	2,104.12	2,058.78	6,616.53	6,611.51	3,493.23

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Elevator drying costs for corn for 10 pts. removed, Purdue Crop Budget, p. 6.

b. Assume interest at 8.5 percent, Purdue Crop Budget, p. 8.

Table A-11. Revenue

Gross revenue was calculated from the expected yield per acre for each crop, the number of acres planted with each crop and the expected price. Expected yields for corn and soybeans vary according to soil type and farming practice. Crops on wetter soil types do not respond as well to decreased tillage as on other soils. Lower yields are expected on the poorer upland soils for all tillage practices. Rotations tend to increase corn yields. Hay yields are responsive to soil types whereas wheat yields are not. Tillage practices for wheat and hay do not vary for the two rotations using them and so yields are not affected. These yields are appropriate for the Black Creek area. The addition of terracing was assumed to create better drainage and to allow one week earlier planting time with yield advantage of one bushel per day.

It should be noted that gross revenue is, of course, very sensitive to the crop prices chosen.

Table A-11. Revenue

	Tillage Practices			Rotations					Terraces[c]		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn											
Expected yield, bu/acre[a]											
A uplands	105	105	99.75	110.25	110.25	110.25	115.50	115.50	112	112	117.25
B ridge	130	130	130	136.50	136.50	136.50	143	143	137	137	143.50
C lowlands	130	130	104	136.50	136.50	122.85	143	135.85	137	137	129.85
Area cropped, acres	250	250	250	125	125	125	62.50	62.50	250	250	125
Total output, bu											
A uplands	26,250	26,250	24,937.50	13,781.25	13,781.25	13,781.25	7,218.75	7,218.75	28,000	28,000	14,656.25
B ridge	32,500	32,500	32,500	17,062.50	17,062.50	17,062.50	8,937.50	8,937.50	34,250	34,250	17,937.50
C lowlands	32,500	32,500	26,000	17,067.25	17,062.50	15,356.25	8,937.50	8,490.63	34,250	34,250	16,231.25
Expected price/ $/bu[b]	2	2	2	2	2	2	2	2	2	2	2
Gross Revenue, $											
A uplands	52,500	52,500	49,875	27,562.50	27,562.50	27,562.50	14,437.50	14,437.50	56,000	56,000	29,312.50
B ridge	65,000	65,000	65,000	34,125	34,125	34,125	17,875	17,875	68,500	68,500	35,875
C lowlands	65,000	65,000	52,000	34,125	34,125	30,712.50	17,875	16,981.26	68,500	68,500	32,462.50
Soybeans											
Expected yield, bu/acre[a]											
A uplands				30	30	27	27	27			29
B ridge				40	40	38	38	38			40
C lowlands				40	36	32	32	32			34
Area cropped, acres				125	125	125	62.5	62.5			125
Total output, bu											
A uplands				3,750	3,750	3,375	1,687.50	1,687.50			3,625
B ridge				5,000	5,000	4,750	2,375	2,375			5,000
C lowlands				5,000	4,500	4,000	2,000	2,000			4,250
Expected price, $/bu[b]				5	5	5	5	5			5
Gross Revenue, $											
A uplands				18,750	18,750	16,875	8,437.50	8,437.50			18,125
B ridge				25,000	25,000	23,750	11,875	11,875			25,000
C lowlands				25,000	22,500	20,000	10,000	10,000			21,250

Table A-11 (continued)

	Tillage Practices			Rotations					Terraces[c]		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Wheat											
Expected yield, bu/acre[a]							45	45			
Area cropped, acres							62.50	62.50			
Total output, bu							2,812.50	2,812.50			
Expected price, $/bu[b]							2.50	2.50			
Gross Revenue, $							7,031.25	7,031.25			
Hay											
Expected yield, tons/acre[a]											
A uplands							3.50	3.50			
B ridge							4	4			
C lowlands							4	4			
Area cropped, acres							62.50	62.50			
Total output, tons											
A uplands							218.75	218.75			
B ridge							250	250			
C lowlands							250	250			
Expected price, $/ton[d]							60	60			
Gross Revenue, $											
A uplands							13,215	13,125			
B ridge							15,000	15,000			
C lowlands							15,000	15,000			
TOTAL GROSS REVENUE, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	43,031.25	43,031.25	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	51,781.25	51,781.25	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	49,906.25	49,012.50	68,500	68,500	53,712.50

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

a. Yield levels based on discussions with Dr. Harry Galloway and Dr. Donald Griffith, Purdue University. Yield reductions for no-till are preliminary and may change with more information. No-till yields are highly dependent on soil type and weed control.

b. Purdue Crop Budget, Department of Agricultural Economics, Purdue University, Lafayette, Indiana, 1977, p. 7.

c. 7 bu/acre corn yield advantage with terracing due to better drainage, 2 bu/acre soybean yield advantage.

d. Based on discussions with Rex Journey, Allen County Soil Conservation District.

Table A-12. Summary

This table is straightforward. All costs were added for each farming practice alternative and then subtracted from gross revenue to give net return. Land costs were not included since these were assumed to be the same for each soil type no matter what farming practice is used. It should be noted, however, that when we eliminated land costs from the summary calculation we eliminated a variable which might tend to equalize return among farmers located on different soils. For example, an upland farm may have much lower land costs than a lowland farm which might counterbalance the differences in net return. Due to the use of a percentage factor added to labor costs to cover farm overheads as well as to the elimination of land costs, the net revenue values are most useful for relative comparisons among alternatives rather than as measures of actual profit.

Table A-12. Summary

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Gross Revenue, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	43,031.25	43,031.25	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	51,781.25	51,781.25	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	49,906.25	49,012.50	68,500	68,500	53,712.50
Costs											
Tractor (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64
Implements (excl. fuel)	10,643.65	10,365.66	8,913.07	11,134.31	10,828.87	9,376.28	14,493.38	13,728.36	10,643.65	10,365.66	9,376.28
Fuel	1,426.99	1,336.54	1,120.86	1,073.97	1,113.78	898.10	1,508.40	1,424.91	1,426.99	1,336.54	898.10
Seed											
A uplands	2,380	2,380	2,500	2,540	2,540	2,667.50	2,882.50	2,912.50	2,380	2,380	2,667.50
B ridge	2,620	2,620	2,740	2,660	2,660	2,787.50	2,942.50	2,972.50	2,620	2,620	2,787.50
C lowlands	2,860	2,860	2,980	2,780	2,780	2,907.50	3,002.50	3,032.50	2,860	2,860	2,907.50
Fertilizer											
A uplands	7,540	7,540	7,947.50	4,658.75	4,658.75	4,843.75	4,000.63	4,060.63	7,540	7,540	4,843.75
B ridge	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8,487.50	5,351.25
C lowlands	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8,487.50	5,351.25
Pesticides											
A uplands	5,705	5,705	11,285	4,540	4,540	6,062.50	2,850.01	3,490.63	5,705	5,705	6,062.50
B ridge	5,225	5,225	10,637.50	3,887.50	3,887.50	5,350	2,513.76	3,154.38	5,225	5,225	5,350
C lowlands	6,187.50	6,187.50	11,930	5,173.75	5,173.75	6,758.75	3,176.25	3,816.88	6,187.50	6,187.50	6,758.75
Labor	2,149.42	2,019.30	1,708.98	1,691.76	1,671.68	1,361.36	2,215.42	2,095.30	2,149.42	2,019.30	1,361.36
Terracing	0	0	0	0	0	0	0	0	6,460	6,460	6,460
Other											
A uplands	5,215.34	5,210.32	5,263.45	2,942.90	2,945.11	3,019.22	1,794.69	1,818.74	5,495.34	5,490.32	3,159.22
B ridge	6,281.02	6,276	6,540.62	3,481.21	3,483.42	3,559.56	2,072.56	2,098.72	6,561.02	6,556	3,699.56
C lowlands	6,336.53	6,3[illegible]1.51	5,569.16	3,542.67	3,544.88	3,353.23	2,104.12	2,058.78	6,616.53	6,611.51	3,493.23
Total Cost (Net of Land Cost)											
A uplands	39,665.31	39,094.24	43,020.05	32,853.95	32,600.14	32,285.35	34,479.74	34,203.48	46,405.31	45,834.24	38,885.35
B ridge	41,438.49	40,867.42	44,949.22	33,307.01	33,053.45	32,740.69	34,661.36	34,414.71	48,178.49	47,607.42	39,340.69
C lowlands	42,696.50	42,125.43	45,510.76	34,774.97	34,521.16	34,063.11	35,415.43	35,097.27	49,436.50	48,865.43	40,663.11
Net Return (Excl. Land Costs)											
A uplands	12,834.69	13,405.76	6,854.95	13,458.55	13,712.36	12,152.15	8,551.51	8,827.77	9,594.69	10,165.76	8,552.15
B ridge	23,561.51	24,132.58	20,050.78	25,817.99	26,071.55	25,134.31	17,119.89	17,366.54	20,321.51	20,892.58	21,534.31
C lowlands	22,303.50	22,874.57	6,489.24	24,350.03	24,603.84	16,649.39	14,490.82	13,915.23	19,063.50	19,634.57	13,049.39

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

Table A-13. Net Revenue Ranking

Table A-13 shows the ranking of the farming practice options according to net revenue, from the highest revenue producing alternative to the lowest. The rankings are shown for each soil type and also for all soil types simultaneously.

For all soil types the corn-soybean chisel plow option is the best, better than conventional tillage although only slightly better. Since gross revenues are the same for both of these options, the difference is caused by the slightly lower equipment costs for the chisel plow option (see Table A-12, Summary).

It is interesting to note that the corn-soybean rotation options using chisel and conventional tillage produce more revenue than continuous corn. This is not primarily due to a favorable corn-soybean price ratio as can be seen from the gross revenue rows in Table A-12. The difference is caused, in large part, by the higher fertilizer and pesticide costs which the addition of soybeans in the rotation helps to reduce. Labor hours are also a factor because harvesting soybeans is quicker than harvesting corn.

The no-till options, for both the corn-soybean rotation and continuous corn, produce less revenue (much less for continuous corn on the uplands and lowlands) than conventional or chisel tillage. This is caused by two factors, a lower yield combined with high pesticide costs. The extra pesticide is needed to kill weeds which are more abundant due to lack of plowing and to eradicate insects which the residue tends to encourage. The no-tillage options are more suited to better drained soils as illustrated by the very good yield for the corn-soybean no-tillage option for the ridge soils in Table A-11 and the correspondingly high net revenue ranking.

The corn-soybean-wheat-meadow rotation options produce less revenue than the corn-soybean and continuous corn options, generally. Even though many costs such as for pesticides are lower for these options and though corn yields are quite high (see Table A-11), the loss of revenue from putting half the acreage into wheat and hay instead of corn or corn and soybeans is so great that the net return for these options is low. Equipment costs are also very high for these rotation options (see Alternative A).

The terrace options produce lower net revenue than the other options because the cost of installing terracing is not outweighed by the yield advantage gained by improved drainage. The terrace options follow the same pattern as the non-terraced options, chisel plowing being more lucrative than conventional tillage and that in turn better than no-tillage except for the ridge farm where the yield advantage of the better drained soils makes this option more attractive.

When all soils are considered together it can be seen that the ridge soils, generally speaking, produce the most revenue, although there is not much of a difference between ridge and lowland soils for conventional and chisel tillage. The small differences between these soils for these two tillage practices is caused by the slightly higher seed and pesticide cost borne by the lowland farms. When the no-tillage practice is employed there is a greater difference in yields between the ridge and lowland soils, caused mainly by the lowered yields on the lowlands. The upland soils are much poorer than the other two soils and are associated with a much lower yield resulting in consistently lower net revenues for all farming practices except no-tillage on the lowlands. This practice is just not suited to a wet, poorly-drained soil, so its poor performance is reflected in a very low net return.

Table A-13. Net Revenue Ranking

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CB Chisel	r	CB Chisel	← 27,000
	CB Conv.	CB Conv.	CB Conv.	r	CB Conv.	
	C Chisel	CB No-till	C Chisel	r	CB No-till	
	C Conv.	C Chisel	C Conv.	l	CB Chisel	← 25,000
	CB No-till	C Conv.	C Chisel-Ter	l	CB Conv.	
	C Chisel-Ter.	CB No-t.-Ter.	C Conv.-Ter.	r	C Chisel	
	C Conv.-Ter.	C Chisel-Ter.	CB No-till	r	C Conv.	← 23,000
	CBWM-Herb.	C Conv.-Ter.	CBWM-Part.	l	C Chisel	
	CB No-t.-Ter.	C No-till	CBWM-Herb.	l	C Conv.	
	CBWM-Part.	CBWM-Herb	CB No-t.-Ter.	r	CB No-till-Ter.	←21,000
low	C No-till	CBWM-Part.	C No-till	r	C Chisel-Ter.	
				r	C Conv.-Ter.	
				r	C No-till	← 20,000
				l	C Chisel - Ter.	
				l	C Conv.-Ter.	
				r	CBWM-Herb.	
				r	CBWM-Part.	← 17,000
				l	CB No-till	
				l	CBWM-Part.	← 14,000
				l	CBWM-Herb.	
				u	CB Chisel	
				u	CB Conv.	
				u	C Chisel	
				l	CB No-till-Ter.	← 13,000
				u	C Conv.	
				u	CB No-till	
				u	C Chisel-Ter.	← 10,000
				u	C Conv.-Ter.	
				u	CBWM-Herb	
				u	CB No-till-Ter.	
				u	CBWM-Part.	← 8,000
				u	C No-till	
				l	C No-till	← 6,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

Table A-14. Soil Loss Ranking

Table A-14 shows the farming practice options ranked according to level of soil loss, expressed in tons per acre, from low losses to high losses. As one would expect, the corn-soybean-wheat-meadow options with half the acreage in a grass cover crop have the lowest soil losses for each of the soil types considered. The partially plowed CBWM option loses more soil than the herbicide option since plowing turns under the meadow sod. The no-tillage practice lowers runoff because more residue remains to retain the water. Terracing is a structural measure which prevents water from flowing off the field as quickly as it otherwise would. Chisel plow options also produce less soil loss than conventional tillage options since more residue remains after chisel plowing than after moldboard plowing which turns the soil completely over. Soil loss on the corn-soybean rotations is higher than on the continuous corn options because soybean residue is not as bulky as corn residue.

Taking all the soils together and ranking the farming practices, shows that, as one would predict, soil loss is greatest for the more erosive upland soils with the greatest slope, less for the ridge, and lowest for the lowlands which have almost no slope. The range of soil loss is quite large, going from less than one ton per acre lost from the corn-soybean-wheat-meadow option on the lowlands to almost 28 tons per acre from the conventionally tilled corn-soybean rotation on the uplands.

As indicated in the footnote on Table A-14, the column showing tons per acre of soil lost from the farming practice options can be used to visualize the effects of a soil loss restriction policy. If a limit were set at two tons per acre, for example, then all the practices ranked below that limit would not be allowed. This policy would have an unequal effect on farms depending on where they are located. It would force all farms located on the uplands and ridge to move to a meadow rotation (this conclusion assumes, of course, that all rotation possibilities available to the farmer have been considered in our ranking). Referring back to Table A-13, Net Revenue Ranking, it can be seen that the farm located on the lowlands would make out the best in terms of profit under such a policy. In fact, farmers owning lowlands would probably experience windfall gains in the short term since their land would become relatively much more valuable. Such a farmer could still use his most profitable option, a chisel plowed corn-soybean rotation. Farmers on the ridge would be forced to switch to one of ther lowest net revenue options; they would lose the most revenue under such a policy. Farmers on the uplands would also lose revenue by switching to a less profitable option. Although they would have the lowest net revenue under this soil loss restriction policy, they also made less in the unrestricted case.

Table A-14

Soil Loss Ranking

	Upland	Ridge	Lowland		All Soils	
Low	CBWM-Herb.	CBWM-Herb.	CBWN-Herb.	l	CBWM-Herb.	
	CBWM-Part.	CBWM-Part.	CBWM-Part.	r	CBWM-Herb.	
	C No-till	C No-till	C No-till	l	CBWM-Part	
	CB No-t.-Ter.	CB No-t.-Ter.	CB No-t.-Ter.	l	C No-till	
	C Chisel-Ter.	C Chisel-Ter.	C Chisel-Ter.	l	CB No-till-Ter.	← 1 ton*
	CB No-till	CB No-till	CB No-till	l	C Chisel-Ter.	
	C Chisel	C Chisel	C Chisel	u	CBWM-Herb.	
	CB Chisel	CB Chisel	CB Chisel	l	CB No-till	
	C Conv.-Ter.	C Conv.-Ter.	C.Conv.-Ter.	l	C Chisel	
	C Conv.	C Conv.	C Conv.	r	CBWM-Part.	
high	CB Conv.	CB Conv.	CB Conv.	l	CB Chisel	← 2 ton
				l	C Conv.-Ter.	
				r	C No.till	
				r	CB No-till-Ter.	
				r	C Chisel-Ter.	← 3 ton
				l	C Conv.	
				l	CB Conv.	
				r	CB No-till	← 4 ton
				r	C Chisel	
				u	CBWM Part.	← 5 ton
				r	CB Chisel	
				r	C Conv.-Ter.	
				u	C No-till	← 8 ton
				u	CB No-till-Ter.	
				u	C Chisel-Ter.	← 9 ton
				r	C Conv.	
				r	CB Conv.	← 10 ton
				u	CB No-till	
				u	C Chisel	
				u	CB Chisel	← 16 ton
				u	C Conv.-Ter.	
				u	C Conv.	
				u	CB Conv.	← 28 ton

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

* If soil loss restrictions of the tonnages given per acre were imposed, then only the farming practices on the soils indicated located above the arrow would be permissible.

Alternative A: Custon Wheat, Hay

This alternative was designed to examine the effects of using custom operations instead of purchasing wheat and hay equipment. It was chosen because it appeared that the base case assumption, that a farmer moving to a corn-soybean-wheat-hay rotation would purchase specialized equipment for planting wheat and harvesting hay, was somewhat unrealistic. This is especially true since the hay is only grown on one quarter of the farm acreage. In fact, the farmer most probably would hire in help and equipment to carry out these operations for him. This was the assumption made in the Alternative A tables.

Table A-3A lists the equipment used in the two corn-soybean-wheat-hay options along with the custom operations and their costs which would be substituted for some of the equipment in the base case example. The rates listed are averages for Northern Indiana and come from the Cooperative Extension Service. The table shows the total equipment and custom operation cost for each alternative which may be compared with the totals in Table A-3.

The total tractor hours for the custom alternatives would not be the same as for the two base case wheat, hay options because of the equipment changes discussed above. Fewer tractor hours would be required to haul fewer implements. Table A-4A shows the altered tractor hour per acre figure and traces the resulting tractor cost charges. Fuel cost would be similarly affected and this is shown in Table A-5A. Labor costs are dependent on tractor hours and are therefore also lowered with the addition of the custom operations. This is illustrated in Table A-9A.

Table A-3A. Machinery Costs -- Custom Wheat, Hay Alternative

Item	Total non-custom cost, $[a]	Custom cost per acre, $[b]	Custom acres	Total Custom cost, $	Total cost, $
Corn-soybeans-wheat-meadow, fall turn-plow corn, fall shred, no-till plant others					
stalk shredder	509.04	-	-	-	509.04
mold board plow	742.52	-	-	-	742.52
disk	1,219.26	-	-	-	1,219.26
harrow	123.31	-	-	-	123.31
sprayer	262.51	-	-	-	262.51
no-till planter	1,080.09	-	-	-	1,080.09
combine corn, soybeans, wheat	5,068.68	-	-	-	5,068.68
corn head	1,400.38	-	-	-	1,400.38
platform	697.48	-	-	-	697.48
custom drilling wheat and meadow	-	3.63	62.5	226.88	226.88
custom hay mowing/conditioning, one operation	-	5.63	62.5	351.88	351.88
custom raking hay	-	2.66	62.5	166.25	166.25
custom baling hay[c] -- uplands	-	25.34	62.5	1,583.75	1,583.75
-- ridge and lowlands	-	28.97	62.5	1,810.63	1,810.63
Total -- uplands	11,103.27	37.26	62.5	2,328.75	13,432.02
-- ridge and lowlands	11,103.27	40.89	62.5	2,555.63	13,658.90
Corn-soybeans-wheat-meadow, fall shred, no-till plant					
stalk shredder	509.04	-	-	-	509.04
disk	1,198.16	-	-	-	1,198.16
harrow	121.91	-	-	-	121.91
sprayer	262.51	-	-	-	262.51
no-till planter	1,080.09	-	-	-	1,080.09
combine corn, soybeans, wheat	5,068.68	-	-	-	5,068.68
corn head	1,400.38	-	-	-	1,400.38
platform	697.48	-	-	-	697.48
custom drilling wheat and meadow	-	3.63	62.5	226.88	226.88
custom hay mowing/conditioning, one operation	-	5.63	62.5	351.88	351.88
custom raking hay	-	2.66	62.5	166.25	166.25
custom baling hay -- uplands	-	25.34	62.5	1,583.75	1,583.75
-- ridge and lowlands	-	28.97	62.5	1,810.63	1,810.63
Total -- uplands	10,338.25	37.26	62.5	2,328.75	12,667.00
-- ridge and lowlands	10,338.25	40.89	62.5	2,555.63	12,893.88

a. From Table 3.

b. Source: Indiana Custom Rates, EC-130 (Rev.), Cooperative Extension Service, Purdue University, West Lafayette, Indiana, 1976. Rates given are average 1976 prices for Northern Indiana; Black Creek Watershed is in Northern Indiana.

c. Custom hay baling rate from above source is $0.21 per 58 lb bale so rates given vary according to yield variations.

Table A-4A

Tractor Costs -- Custom Wheat, Hay Alternative

Item	CBWM Partial No-till	CBWM No-till Herbicide
Tractor hours per acre[a]	.79	.68
Total tractor hours[b]	217.25	187.00
Tractor initial costs, $[b]	23,600.00	23,600.00
Economic life, years[b]	14	15
Salvage value, percent[b]	21.5	19.5
Yearly depreciation, $	1,323.29	1,266.53
Taxes, insurance & housing, $[b]	1,062.00	1,062.00
Average annual interest, $[b]	1,146.96	1,128.08
Total fixed costs, $	3,532.25	3,456.08
Repair costs, $[b]	410.17	353.06
Total tractor costs, $ (excluding fuel)	3,942.42	3,809.14

Notes: CBWM = corn-bean-wheat-meadow.

a. Tractor hours per acre from Table A-4, minus hours per acre for implements replaced by custom operations.

b. See footnotes to Table A-4.

Table A-5A

Fuel Costs -- Custom Wheat, Hay Alternative

Item	CBWM Partial No-till	CBWM No-till Herbicide
Total tractor hours[a]	217.25	187.00
Fuel cost per tractor hour, $[b]	2.53	2.53
Tractor fuel cost, $	549.64	473.11
Combine fuel cost, $[c]	137.77	137.77
Total fuel cost, $	687.41	610.88

Notes: CBWM = corn-bean-wheat-meadow.

[a] From Table A-5.

[b] See footnotes to Table A-5.

[c] Derivation shown in Table A-5.

Table A-9A

Labor Costs -- Custom Wheat, Hay Alternative

Item	CBWM Partial No-till	CBWM No-till Herbicide
Total direct labor, hours*	284.13	253.88
Overhead (30 percent), hours	85.24	76.16
Total labor, hours	369.37	330.04
Cost per hour, $*	2.80	2.80
Total labor costs, $	1,034.24	924.11

Notes: CBWM = corn-bean-wheat-meadow.

* See footnotes to Table A-9. Tractor hours from Table A-4A.

Since fuel and labor costs have been decreased, interest on operating capital for financing these input factors is correspondingly decreased, as shown in Table A-10A.

Table A-12A summarizes all the changes discussed above and shows a new net revenue figure for each corn-bean-wheat-hay rotation. Hiring in custom operators yields approximately a 45 percent increase in revenue for a farm located on the upland soils and about an 24 percent increase for a farm on the ridge or lowland soils.

The increase in net revenue produced by substituting custom operations for purchase of certain equipment results in an improvement in position of the two wheat, hay rotations in comparison to the other farming practices considered. If Table A-13A is compared with Table A-13, Net Revenue Ranking, it can be seen that the CBWM options move up on the ranking list for each soil type, from 7 and 9 to 5 and 6 for the uplands farm, from 10 and 11 to 7 and 9 for the ridge and from 8 and 9 to 7 and 8 for the lowlands. In the ranking for all soils, the highest CBWM option moves from the sixteenth to the eleventh spot. It can be concluded from this comparison that although the substitution of custom operations for the purchase of wheat and hay equipment certainly improves the attractiveness of this rotation option in comparison to the more common farming practices, it alone does not improve net revenue enough to put it in a competitive position.

Table A-10A

Other Costs -- Custom Wheat, Hay Alternative

Item	CBWM Partial No-till	CBWM No-till Herbicide
Corn drying Costs[a]		
A uplands	1155	1155
B ridge	1430	1430
C lowlands	1430	1358.50
Interest on Operating Capital[b]		
Fuel (3 months)[c]	14.61	12.98
Labor (3 months)[d]	13.06	10.43
Other interest[e]		
A uplands	590.52	619.21
B ridge	593.39	624.19
C lowlands	624.95	655.75
Total interest		
A uplands	618.19	642.62
B ridge	621.06	647.60
C lowlands	652.62	679.16
Total Other Costs		
A uplands	1,773.19	1,797.62
B ridge	2,051.06	2,077.60
C lowlands	2,082.62	2,037.66

Notes: CBWM = corn-bean-wheat-meadow.

a. Derivation shown in Table A-10.

b. See footnotes to Table A-10.

c. Fuel costs from Table A-5A.

d. Labor costs from Table A-9A.

e. From Table A-10.

Table A-12A

Summary -- Custom Wheat, Hay Alternative

Item	CBWM Partial No-till	CBWM No-till Herbicide
Gross revenue, $*		
A uplands	43,031.25	43,031.25
B ridge	51,781.25	51,781.25
C lowlands	49,906.25	49,012.50
Costs		
Tractor (excluding fuel)**	3,942.42	3,809.14
Implements (excluding fuel)***		
A uplands	13,432.02	12,667.00
B ridge	13,658.90	12,893.88
C lowlands	13,658.90	12,893.88
Fuel+	687.41	610.88
Labor++	1,034.24	924.11
Drying and interest costs+++		
A uplands	1,773.19	1,797.62
B ridge	2,051.06	2,077.60
C lowlands	2,082.62	2,037.66
Other Costs*		
A uplands	9,733.14	10,463.76
B ridge	9,636.89	10,395.01
C lowlands	10,359.40	11,117.51
Total cost (net of land cost)		
A uplands	30,602.42	30,272.51
B ridge	31,010.92	30,710.62
C lowlands	31,764.99	31,393.18
Net return (excluding land costs)		
A uplands	12,428.83	12,758.74
B ridge	20,770.33	21,070.63
C lowlands	18,141.26	17,619.32

Notes: CBWM = corn-bean-wheat-meadow.

* From Table A-12.

** From Table A-4A.

*** From Table A-3A.

+ From Table A-5A.

++ From Table A-9A.

+++ From Table A-10A.

Table A-13A

Net Revenue Ranking -- Custom Wheat, Hay Alternative

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CH Chisel	r	CB Chisel	← 27,000
	CB Conv.	CB Conv.	CB Conv.	r	CB Conv.	← 25,000
	C Chisel	CB No-till	C Chisel	r	CB No-till	
	C Conv.	C Chisel	C Conv.	l	CB Chisel	
	CBWM-Herb.	C Conv.	C Chisel-Ter.	l	CB Conv.	
	CBWM-Part.	CB No.-t.Ter.	C Conv.-Ter.	r	C Chisel	
	CB No-till	CBWM-Herb.	CBWM-Part.	r	C Conv.	← 23,000
	C Chisel-Ter.	C Chisel-Ter.	CBWM-Herb.	l	C Chisel	
	C Conv.-Ter.	CBWM-Part.	CB No-till	l	C Conv.	
	CB No-t.-Ter.	C Conv.-Ter.	CB No-t.Ter.	r	CB No-till Ter.	
low	C No-till	C No-till	C No-till	r	CBWM-Herb.	← 21,000
				r	C Chisel-Ter.	
				r	CBWM-Part.	
				r	C Conv.-Ter.	
				r	C No-till	← 20,000
				l	C Chisel-Ter.	
				l	C Conv.-Ter.	
				l	CBWM-Part.	
				l	CBWM-Herb.	
				l	CB No-till	← 15,000
				u	CB Chisel	
				u	CB Conv.	
				u	C Chisel	
				l	CB No-t.-Ter.	← 13,000
				u	C Conv.	
				u	CBWM-Herb.	
				u	CBWM-Part.	
				u	CB No-till	
				u	C Chisel-Ter.	← 10,000
				u	C Conv.-Ter.	
				u	CB No-t.-Ter.	← 8,000
				u	C No-till	
				l	C No-till	← 6,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean=wheat-meadow.

r = ridge; l = lowlands; u = uplands.

Alternative B: Energy Cost Increase

Alternative B assumes a future scenario in which energy prices have increased while other costs have remained constant. The B Alternative examines the effects of this cost increase on the farmer's factors of production and on his net return.

Table A-5B illustrates the method used to develop the energy price increase. Tractor fuel cost and combine fuel cost per hour have been increased by a factor of 2.068. This factor was derived from the annual price change rates for the years 1977 through 1985 for crude oil (refiner acquisition). The source of these projections is Energy Review, Summer 1977, published by Data Resources, Inc., Lexington, Massachusetts. Total fuel cost was calculated in the same way for Table A-5B as for Table A-5.

Table A-7B shows how fertilizer costs have been increased. A different price increase factor was used for each type of fertilizer depending upon the relative amounts of different energy inputs used in its production. It was assumed that other inputs to the production of fertilizer such as marketing, administration, and labor were either a very small component of the total cost or would move proportionally to the energy cost. Therefore the price of the fertilizer to the farmer was assumed to increase at the same rate as that of the energy inputs to fertilizer production. (This same assumption was made for pesticide costs, corn drying costs, and fuel costs.) Sources of the percentages of energy inputs to fertilizer production are given in the footnotes to Table A-7B. The energy price increase factors were developed from projections from the same source as for the fuel increase factor, above. Energy input

Table A-5B. Fuel Costs -- Increased Energy Cost Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Total tractor hours	473.00	437.25	352.00	347.27	363.00	277.75	541.75	508.75	473.00	437.25	277.75
Fuel cost per tractor hour, $*	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23
Tractor fuel cost, $	2474.75	2287.70	1841.68	1816.92	1899.23	1453.20	2,833.35	2,660.76	2474.75	2287.70	1453.20
Total combine hours	117.50	117.50	117.50	96.25	96.25	96.25	66.88	66.88	117.50	117.50	96.25
Fuel cost per combine hour, $*	4.05	4.05	4.05	4.20	4.20	4.20	4.26	4.26	4.05	4.05	4.20
Combine fuel cost, $	476.26	476.26	476.26	404.07	404.07	404.07	284.91	284.91	476.26	476.26	404.07
Total fuel cost, $	2951.02	2763.96	2317.94	2220.97	2303.30	1857.27	3,118.26	2,945.67	2951.02	2763.96	1857.27

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* For derivation see footnotes, Table A-5. Assume 1985/1977 price ratio of 2.068, developed from annual price change data for crude oil (refiner acquisition) from Energy Review, Summer 1977, Data Resources Inc., Lexington, Massachusetts.

Table A-7B. Fertilizer Costs -- Increased Energy Cost Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Average annual Fertilizer amount, lbs/acre*											
N											
A uplands	125	125	137.50	57.50	57.50	63.25	33.75	35.63	125	125	63.25
B ridge	160	160	176	75	75	82.50	42.50	45.25	160	160	82.50
C lowlands	160	160	176	75	75	82.50	42.50	45.25	160	160	82.50
P_2O_5											
A uplands	44	44	44	27.50	27.50	27.50	24.75	24.75	44	44	27.50
B ridge	40	40	40	25	25	25	22.50	22.50	40	40	25
C lowlands	40	40	40	25	25	25	22.50	22.50	40	40	25
K_2O	50	50	50	60	60	60	70	70	50	50	60
Cost of Fertilizer**											
N											
A uplands	34.92	34.92	38.42	16.06	16.06	17.67	9.43	9.96	34.92	34.92	17.67
B ridge	44.70	44.70	49.17	20.96	20.96	23.05	11.88	12.64	44.70	44.70	23.05
C lowlands	44.70	44.70	49.17	20.96	20.96	23.05	11.88	12.64	44.70	44.70	23.05
P_2O_5											
A uplands	17.06	17.06	17.06	10.67	10.67	10.67	9.59	9.59	17.06	17.06	10.67
B ridge	15.51	15.51	15.51	9.69	9.69	9.69	8.74	8.74	15.51	15.51	9.69
C lowlands	15.51	15.51	15.51	9.69	9.69	9.69	8.74	8.74	15.51	15.51	9.69
K_2O	9.22	9.22	9.22	11.06	11.06	11.06	12.90	12.90	9.22	9.22	11.06
Cost of Fertilizer per acre, $											
A uplands	61.20	61.20	64.70	37.79	37.79	39.40	31.92	32.45	61.20	61.20	39.40
B ridge	69.43	69.43	73.90	41.71	41.71	43.80	33.52	34.28	69.43	69.43	43.80
C lowlands	69.43	69.43	73.90	41.71	41.71	43.80	33.52	34.28	69.43	69.43	43.80
Total cost of Fertilizer, $											
A uplands	15,300	15,300	16,175	9,447.50	9,447.50	9,850	7,980	8,112.50	15,300	15,300	9,850
B ridge	17,357.50	17,357.50	18,475	10,427.50	10,427.50	10,950	8,380	8,570	17,357.50	17,357.50	10,950
C lowlands	17,357.50	17,357.50	18,475	10,427.50	10,427.50	10,950	8,380	8,570	17,357.50	17,357.50	10,950

Table A-7B (continued)

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Rental of application equipment, $*	262.50	262.50	262.50	131.25	131.25	131.25	153.13	153.13	262.50	262.50	131.25
Total Fertilizer Costs, $											
A uplands	15,562.50	15,562.50	16,437.50	9,578.75	9,578.50	9,981.25	8,133.13	8,265.63	15,562.50	15,562.50	9,981.25
B ridge	17,620	17,620	18,737.50	10,558.75	10,558.75	11,081.25	8,533.13	8,723.13	17,620	17,620	11,081.25
C lowlands	17,620	17,620	18,737.50	10,558.75	10,558.75	11,081.25	8,533.13	8,723.13	17,620	17,620	11,081.25

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* For derivation see Table A-7B; see footnotes, Table A-7B.

** Cost of fertilizer derived from fertilizer prices from Table 7 multiplied by the following 1985/1975 price ratios: N -- 2.149; P_2O_5 -- 2.041; K_2O -- 2.048. Fertilizer price ratios are produced by multiplying energy input amounts by energy input price ratios. Energy inputs to N: 95% natural gas; 5% electricity (Source: Davis, C. H. and G. M. Blouin, "Energy Consumption in the U.S. Chemical Fertilizer System from the Ground to the Ground," p. 321 in W. L. Lockertz (ed.), Agriculture and Energy, Academic Press, New York, 1977.) Energy inputs to P_2O_5: 18% oil, 69% natural gas, 11% electricity (percents developed from data in White, W. C. and K. T. Johnson, Energy Requirements for the Production of Phosphate Fertilizers, Draft, The Fertilizer Institute, Washington, D.C. (no date)). Energy inputs to K_2O: 81% natural gas, 11% electricity (percents developed from data in White, W. C., "Fertilizer-Food-Energy Relationships," paper presented at the American Chemical Society Division of Fertilizer and Soil Chemistry, Chicago, Illinois, August 28, 1973). 1985/1977 price ratios for natural gas (industrial), electrictiy (marginal industrial), and crude oil (refiner acquisition) of 2.185, 1.462, and 2.068, respectively, developed from annual price change data from Energy Review, Summer 1977, Data Resources, Inc., Lexington, Massachusetts.

percentages were multiplied by energy price increase factors and then summed to obtain the price increase factor for each type of fertilizer.

Pesticide cost increases are given in Table A-8B and were calculated in the same way as fertilizer cost increases. All pesticide costs are assumed to increase by the same factor, 2.013, since the percentages of energy inputs are assumed to be the same for all. The source of this information is listed in the footnote to Table A-8B which also lists the energy price increase factors and their source.

Corn drying costs (Table A-10B) are increased due to increased energy cost. Off-farm corn drying is based on energy from LP gas and natural gas. A price increase ratio of 2.127 was used for corn drying. The first footnote to Table A-10B lists the sources of data from which this figure was calculated. Table A-10B also shows increased interest costs necessary to support more operating capital needed to finance the increased fertilizer, pesticide and fuel expenses which the farmer encounters in this scenario.

Table A-12B summarizes the energy cost increase alternative showing higher fuel, fertilizer, pesticide and "other" costs. Total costs in Table A-12B when compared with Table A-12 have increased from between $10,000 and $30,000 or 30 to 65 percent. These high cost increases, of course, affect net return drastically. As the "net return" figures indicate, many options are no longer financially viable.

Table A-13B shows how increased energy costs have affected the ranking of the options in terms of net revenue. Only 11 out of 33 options produce a positive return, and one of these is below $1,000. Farmers on the up-

Table A-8B. Pesticide Costs — Increased Energy Cost Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
CORN											
Total Herbicide and Insecticide Cost, $*											
A uplands	11,484.17	11,484.17	22,716.71	5,676.66	5,676.66	8,442.16	3,856.16	5,145.73	11,484.17	11,484.17	8,442.02
B ridge	10,517.93	10,517.93	21,412.28	5,193.54	5,193.54	7,878.38	3,614.60	4,904.17	10,517.93	10,517.93	7,878.38
C lowlands	12,455.44	12,455.44	24,015.09	6,071.71	6,071.71	9,015.72	4,098.97	5,388.56	12,455.44	12,455.44	9,015.72
SOYBEAN											
Total Herbicide Cost, $*											
A uplands				3,462.36	3,462.36	3,761.79	1,880.91	1,880.91			3,761.79
B ridge				2,632	2,632	2,891.17	1,445.60	1,445.60			2,891.17
C lowlands				4,252.46	4,252.46	4,589.64	2,294.82	2,294.82			4,589.64
Total Pesticide Cost, $											
A uplands	11,484.17	11,484.17	22,716.71	9,139.02	9,139.02	12,203.81	5,737.07	7,026.64	11,484.17	11,484.17	12,203.81
B ridge	10,517.93	10,517.93	21,412.28	7,825.54	7,825.54	10,769.55	5,060.20	6,349.77	10,517.93	10,517.93	10,769.55
C lowlands	12,455.44	12,455.44	24,015.09	10,414.76	10,414.76	13,605.36	6,393.79	7,683.38	12,455.44	12,455.54	13,605.36

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* For derivation of pesticide amounts see Table 8 and footnotes to Table 8. Pesticide costs have been increased using a 1985/1977 price ratio of 2.013. This price ratio was developed by multiplying pesticide energy input amounts by energy input price ratios. Energy inputs to the production of pesticides are 42% oil, 38% natural gas, 20% coal (Source: Pimentel, David, Energy Inputs for the Production, Formulation, Packaging and Transport of Various Pesticides, Draft, November 1977, p. 3). 1985/1977 price ratios for crude oil (refiner acquisition), natural gas (industrial), and coal (contract) of 2.068, 2.185, and 1.568, respectively, were developed from annual price change data from Energy Review, Summer 1977, Data Resources, Inc., Lexington, Massachusetts.

Table A-10B. Others Costs -- Energy Cost Increase Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn Drying											
Grain harvested, bu											
A uplands	26,250	26,250	24,937.50	13,781.25	13,781.25	13,781.25	7,218.75	7,218.75	28,000	28,000	14,656.25
B ridge	32,500	32,500	32,500	17,062.50	17,062.50	17,062.50	8,937.50	8,937.50	34,250	34,250	17,937.50
C lowlands	32,500	32,500	26,000	17,062.50	17,062.50	15,356.25	8,937.50	8,490.63	34,250	34,250	16,231.25
Cost per bu, $*	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34
Total Cost*											
A uplands	8,933.40	8,933.40	8,486.73	4,690.04	4,690.04	4,690.04	2,456.69	2,456.69	9,528.96	9,528.96	4,987.82
B ridge	11,060.40	11,060.40.	11,060.40	5,806.71	5,806.71	5,806.71	3,041.61	3,041.61	11,655.96	11,655.96	6,104.49
C uplands	11,060.40	11,060.40	8,848.32	5,806.71	5,806.71	5,226.04	3,041.61	2,889.53	11,655.96	11,655.96	5,523.82
Interest on Operating Capital**											
Fertilizer (8 mo.)***											
A uplands	1,190.53	1,190.53	1,257.47	732.77	732.77	763.57	622.18	632.32	1,190.53	1,190.53	763.57
B ridge	1,347.93	1,347.93	1,433.42	807.74	807.74	847.72	652.78	667.32	1,347.93	1,347.93	847.72
C lowlands	1,347.93	1,347.93	1,433.42	807.74	807.74	847.72	652.78	667.32	1,347.93	1,347.93	847.72
Seed (8 mo.)											
A uplands	134.87	134.87	141.67	143.93	143.93	151.16	163.34	160.22	134.87	134.87	151.16
B ridge	148.47	148.47	155.27	150.73	150.73	157.96	166.74	163.62	148.47	148.47	157.96
C lowlands	162.07	162.07	168.87	157.53	157.53	164.76	170.14	167.02	162.07	162.07	164.76
Pesticide (6 mo.)+											
A uplands	488.08	488.08	965.46	388.41	388.41	518.66	243.83	298.63	488.08	488.08	518.66
B ridge	447.01	447.01	910.02	332.59	332.59	457.71	215.06	269.87	447.01	447.01	457.71
C lowlands	529.36	529.36	1,020.64	442.63	442.63	578.23	271.74	326.54	529.36	529.36	578.23
Fuel (3 mo.)++	62.71	58.73	49.26	47.20	48.96	39.47	66.26	62.60	62.71	58.73	39.47
Labor (3 mo.)	30.88	[illegible]	20.37	21.81	23.17	15.77	17.12	14.25	30.88	27.78	15.77
Total Interest											
A uplands	1,906.57	1,899.49	2.434.23	1,334.12	1,337.24	1,488.63	1,112.73	1,168.02	1,906.57	1,899.49	1,488.63
B ridge	2,037.00	2,029.92	2,568.34	1,360.07	1,363.19	1,518.63	1,117.96	1,177.66	2,037.00	2,029.92	1,518.63
C lowlands	2,132.95	2,125.87	2,692.56	1,476.91	1,480.03	1,645.95	1,178.04	1,237.73	2,132.95	2,125.87	1,645.95
Total Other Costs											
A uplands	10,839,97	10,832.89	10,920.96	6,024.16	6,027.28	6,178.67	3,569.42	3,624.71	11,435.53	11,428.45	6,476.45
B ridge	13,097.40	13,090.32	13,628.74	7,166.78	7,169.90	7,325.34	4,159.57	4,219.27	13,692.96	13,685.88	7,623.12
C lowlands	13,193.35	13,186.27	11,540.88	7,283.62	7,286.74	6,871.99	4,219.65	4,127.26	13,788.91	13,781.83	7,169.77

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* For initial price and cost derivation see Table 10. Price and cost have been increased using a 1985/1977 price ratio of 2.127 derived by multiplying the energy input amounts to off-farm corn drying (50% LP gas and 50% natural gas, U.S. Food and Fiber Sector, U.S. Senate Report, September 1974) by 1985/1977 price ratios for crude oil (refiner acquisition) and natural gas (industrial) of 2.068 and 2.185, respectively. These price ratios were developed from annual price change data in Energy Review, Summer 1977, Data Resources, Inc., Lexington, Massachusetts.

** See footnotes in Table A-10, ***Fertilizer costs from Table A-7B, +Pesticide costs from Table A-8B, ++Fuel costs from Table A-5B.

Table A-12B. Summary -- Energy Cost Increase Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Gross Revenue, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	43,031.25	43,031.25	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	51,781.25	51,781.25	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	49,906.25	49,012.50	68,500	68,500	53,712.50
Costs											
Tractor (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64
Implements (excl. fuel)	10,643.65	10,365.66	8,913.07	11,134.31	10,828.87	9,376.28	14,493.38	13,728.36	10,643.65	10,365.66	9,376.28
Fuel*	2,951.02	2,763.96	2,317.94	2,220.97	2,303.30	1,857.27	3,118.26	2,945.67	2,951.02	2,763.96	1,857.27
Seed											
A uplands	2,380	2,380	2,500	2,540	2,540	2,667.50	2,882.50	2,912.50	2,380	2,380	2,667.50
B ridge	2,620	2,620	2,740	2,660	2,660	2,787.50	2,942.50	2,972.50	2,620	2,620	2,787.50
C lowlands	2,860	2,860	2,980	2,780	2,780	2,907.50	3,002.50	2,032.50	2,860	2,860	2,907.50
Fertilizer**											
A uplands	15,562.50	15,562.50	16,437.50	9,578.75	9,578.75	9,981.25	8,133.13	8,265.63	15,562.50	15,562.50	9,981.25
B ridge	17,620	17,620	18,737.50	10,558.75	10,558.75	11,081.25	8,533.13	8,723.13	17,620	17,620	11,081.25
C lowlands	17,620	17,620	18,737.50	10,558.75	10,558.75	11,081.25	8,533.13	8,723.13	17,620	17,620	11,081.25
Pesticides***											
A uplands	11,484.17	11,484.17	22,716.71	9,139.02	9,139.02	12,203.81	5,737.07	7,026.64	11,484.17	11,484.17	12,203.81
B ridge	10,517.93	10,517.93	21,412.28	7,825.54	7,825.54	10,769.55	5,060.20	6,349.77	10,517.93	10,517.93	10,769.55
C lowlands	12,455.44	12,455.44	24,015.09	10,414.76	10,414.76	13,605.36	6,393.79	7,683.38	12,455.44	12,455.44	13,605.36
Labor	2,149.42	2,019.30	1,708.98	1,691.76	1,671.68	1,361.36	2,215.42	2,095.30	2,149.42	2,019.30	1,361.36
Terracing	0	0	0	0	0	0	0	0	6,460	6,460	6,460
Other+											
A uplands	10,839.97	10,832.89	10,920.96	6,024.16	6,027.28	6,178.67	3,569.42	3.624.71	11,435.53	11,428.45	6,476.45
B ridge	13,097.40	13,090.32	13,628.74	7,166.78	7,169.90	7,325.34	4,159.57	4,219.27	13,692.96	13,685.88	7,623.12
C lowlands	13,193.35	13,186.27	11,540.88	7,283.62	7,286.74	6,871.99	4,219.65	4,127.26	13,788.91	13,781.83	7,169.77
Total Cost (Net of Land Cost)											
A uplands	60,615.64	59,945.90	69,796.35	46,601.23	46,390.85	47,682.78	44,883.89	45,271.22	67,671.20	67,001.46	54,440.56
B ridge	64,204.33	63,534.59	70,999.70	47,530.37	47,319.99	48,615.19	45,257.17	45,706.41	71,259.89	70,590.15	55,372.97
C lowlands	66,477.79	65,808.05	74,494.65	50,356.43	50,146.05	51,117.65	46,710.84	47,008.01	73,533.35	72,863.61	57,875.43
Net Return (Excl. Land Cost)											
A uplands	-8,115.64	-7,445.90	-19,921.35	-288.73	-78.35	-3,245.28	-1,852.64	-2,239.97	-11,671.20	-11,001.46	-7,003.06
B ridge	795.67	1,465.41	-5,999.70	11,594.63	11,805.01	9,259.81	6,524.08	6,074.84	-2,759.89	-2,090.15	-5,307.83
C lowlands	-1,477.79	-808.05	-22,494.65	8,768.57	8,978.95	-405.15	3,195.41	2,004.49	-5,033.35	-4,363.61	-4,162.93

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

*Fuel costs from Table A-5B, **Fertilizer costs from Table A-7B, ***Pesticide costs from Table A-8B, +Other costs from Table A-10B.

Table A-13B

Net Revenue Ranking -- Energy Cost Increase Alternative

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CB Chisel	r	CB Chisel	← 12,000
	CB Conv.	CB Conv.	CB Conv.	r	CB Conv.	
	CBWM-Part.	CB No-till	CBWM-Part.	r	CB No-till	← 9,000
	CBWM-Herb.	CBWM-Part.	CBWM-Herb.	l	CB Chisel	
	CB No-till	CBWM-Herb.	CB No-till	l	CB Conv.	
	CB No-t.-Ter.	C Chisel	C Chisel	r	CBWM-Part.	
	C Chisel	C Conv.	C Conv.	r	CBWM-Herb.	← 6,000
	C Conv.	C Chisel-Ter.	CB No-t.-Ter.	l	CBWM-Part	
	C Chisel-Ter.	C Conv.-Ter	C Chisel-Ter	l	CBWM-Herb	← 2,000
	C Conv.-Ter.	CB No-t.-Ter.	C Conv.-Ter.	r	C Chisel	← 1,000
low	C No-till	C No-till	C No-till	r	C Conv	
				u	CB Chisel	
				u	CB Conv.	
				l	CB No-till	
				l	C Chisel	← -3,000
				l	C Conv.	
				u	CBWM-Part.	
				r	C Chisel-Ter.	
				u	CBWM-Herb.	
				r	C Conv.-Ter.	← -3,000
				u	CB No-till	
				l	CB No-t.-Ter.	
				l	C Chisel-Ter.	← -5,000
				l	C Conv.-Ter.	
				r	CB No-till-Ter.	
				r	C No-till	← -6,000
				u	CB No-t.-Ter.	
				u	C Chisel	
				u	C Conv.	← -9,000
				u	C Chisel-Ter.	
				u	C Conv.-Ter.	← -12,000
				u	C No-till	← -20,000
				l	C No-till	← -23,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

lands no longer have revenue producing options available to them. The CBWM options are the least energy intensive and their costs increase the least so they move up in rank for all soil types. On the uplands, they move from seventh and ninth place to third and fourth place. They also rank high on the other two soil types moving from tenth and eleventh place to fourth and fifth place on the ridge and from eighth and ninth place to third and fourth place on the lowlands when compared to the base case (Table A-13).

Revenue from the corn-soybean rotations, chisel and conventionally tilled on the ridge and lowlands, is high and their use of energy intensive factors of production such as fertilizer and pesticides is relatively low compared to continuous corn, for example, so that these options remain the most attractive financially. This is also true for the corn-soybean no-tillage rotation on the ridge soil. In contrast, the continuous corn options, both conventionally and chisel tilled, use relatively more of the energy intensive factors of production, enough to negate the effect of their high gross revenues. The energy price increase in this instance serves to highlight the natural benefits provided by the soybeans to the corn in the form of pest control and nitrogen fertilizer credit.

Table A-15B shows the effects of combining the energy price increase future scenario with alternative A, the use of custom hiring to carry out certain operations in the corn-soybean-wheat-hay rotation options. The costs and revenues for the two options displayed in this table offer perhaps a more realistic picture of the effect of a large energy price increase. Both options become relatively more attractive financially in comparison

Table A-15B. CBWH Farm Practice with Custom Rate and 1985 Energy Prices

	1977			1985	
	Custom Option	Non Custom	$R_{77} = \frac{\text{Custom}}{\text{Non Custom}}$	Non Custom	Custom = R_{77} x Non Custom_{85}
Tractor	3,942	4,735	.833	4,735	3,942
Implements					
A	13,432	14,493	.927	14,493	13,432
B	13,659	14,493	.943	14,493	13,659
C	13,659	14,493	.943	14,493	13,659
Fuel	687	1,508	.456	3,118	1,422
Seed					
A		2,882	1.0	2,882	2,882
B		2,942	1.0	2,942	2,942
C		3,002	1.0	3,002	3,002
Fertilizer					
A		4,001	1.0	8,133	8,133
B		4,181	1.0	8,533	8,533
C		4,181	1.0	8,533	8,533
Biocides					
A		2,850	1.0	5,737	5,737
B		2,514	1.0	5,060	5,060
C		3,176	1.0	6,394	6,394
Labor	1,034	2,215	.467	2,215	1,034
Drying & Intr't					
A	1,773	1,795	.988	3,569	3,526
B	2,051	2,073	.989	4,160	4,114
C	2,083	2,104	.990	4,220	4,174
Total Cost					
A		34,480		44,884	42,985
B		34,661		45,257	43,583
C		35,415		46,711	45,037
Gross Revenue					
A				43,031	43,031
B				51,781	51,781
C				49,906	49,906
Net Revenue					
A	12,429	8,552		-1,852	+46
B	20,770	17,120		+6,524	+8,198
C	18,141	14,491		+3,195	+4,869

Table A-15B. Continued.

	1977			1985	
	Custom Option	Non Custom	$R_{77} = \frac{\text{Custom}}{\text{Non Custom}}$	Non Custom	Custom = R_{77} x Non Custom_{85}
Tractor	3,809	4,672	.815	4,672	3,809
Implements					
A	12,667	13,728	.923	13,728	12,667
B	12,894	13,728	.939	13,728	12,894
C	12,894	13,728	.939	13,728	12,894
Fuel	611	1,425	.429	2,946	1,263
Seed					
A	No change	2,912	1.0	2,912	2,912
B		2,972		2,972	2,972
C		3,032		2,032	2,032
Fertilizer					
A	No Change	4,061	1.0	8,265	8,266
B		4,268		8,723	8,723
C		4,268		8,723	8,723
Biocides					
A	No Change	3,491	1.0	7,027	7,027
B		3,154		6,350	6,350
C		3,817		7,683	7,683
Labor	924	2,095	.441	2,095	924
Drying & Intr't					
A	1,798	1,819	.989	3,625	3,585
B	2,078	2,099	.990	4,219	4,177
C	2,038	2,059	.990	4,127	4,086
Total Cost					
A	30,273	34,203		45,271	40,453
B	30,711	34,415		45,706	41,112
C	31,393	35,097		47,008	41,414
Gross Revenue					
A		43,031		43,031	43,031
B		51,781		51,781	51,781
C		49,012		49,012	49,012
Net Revenue					
A	12,759	8,828		- 2,240	+ 2,578
B	21,071	17,367		+ 6,075	+ 10,669
C	17,619	13,915		2,004	+ 7,598

to other practices. The upland farmer, for example, could use the CBWM no-till option to produce a positive net return.

It can be concluded from this example that a large energy price increase would have severe consequences to farmers causing them to switch to farming practices which are less energy intensive, to relocate or remove land from production, and to increase use of natural rather than manufactured means of adding nutrients to the soil and of pest control. Note, however, that the results of this alternative are extreme, and in reality an energy price increase such as this would have other effects on other costs and on food prices so that the results would be somewhat different than those of the simplified case considered here. But this case does serve to illustrate the direction of the effects of a large energy price increase.

Alternative C: Price Subsidy

Alternative C examines the effect of a price subsidy policy for wheat. Tables A-3 and A-14 show that although the wheat-hay rotations produce relatively little soil loss compared to other options, they are not as attractive in terms of revenue as the continuous corn or the corn-soybean rotations. In Alternative C, a price subsidy mechanism was used to make the wheat-hay rotation options more attractive compared to the highest net revenue producing options in the initial case. The corn-soybean rotation was already more financially appealing than the continuous corn option (see Table A-12), so it was not considered useful to examine a soybean price subsidy.

Table A-11C shows the price of wheat subsidized to $5.00 (a subsidy of $2.50 per acre) which doubles the gross revenue from the acres planted with wheat in the wheat-hay rotation options. The total gross revenue from these options is thus increased by about $7,000 or 15 percent. The wheat/corn price ratio has been changed from 1.25 to 2.5 and the wheat/soybean price ratio from 0.5 to 1.0.

Table A-12C shows a relatively higher net return for the two wheat-hay rotation options compared to the initial case (compare with Table A-12). Table A-13C indicates how this increased net return has shifted the net revenue ranking of the CBWM options when compared to Table A-13, Net Revenue Ranking. For the uplands they have moved from seventh and ninth place to first and second, for the ridge from tenth and eleventh to fourth and fifth and for the lowlands from eighth and ninth to fifth and sixth. The ranking for all soils shows that the highest revenue

Table A-11C. Revenue -- Price Subsidy Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn											
Gross Revenue, $*											
A uplands	52,500	52,500	49,875	27,562.50	27,562.50	27,562.50	14,437.50	14,437.50	56,000	56,000	29,312.50
B ridge	65,000	65,000	65,000	34,125	34,125	34,125	17,875	17,875	68,500	68,500	35,875
C lowlands	65,000	65,000	52,000	34,125	34,125	30,712.50	17,875	16,981.26	68,500	68,500	32,462.50
Soybeans											
Gross Revenue, $*											
A uplands				18,750	18,750	16,875	8,437.50	8,437.50			18,125
B ridge				25,000	25,000	23,750	11,875	11,875			25,000
C lowlands				25,000	22,500	20,000	10,000	10,000			21,250
Wheat											
Expected yield, bu/acre							45	45			
Area cropped, acres							62.50	62.50			
Total output, bu							2,812.50	2,812.50			
Expected price, $/bu**							5.00	5.00			
Gross Revenue, $							14,062.50	14,062.50			
Hay											
Gross Revenue, $*											
A uplands							13,125	13,125			
B ridge							15,000	15,000			
C lowlands							15,000	15,000			
TOTAL GROSS REVENUE, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	50,062.50	50,062.50	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	58,812.50	58,812.50	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	56,937.50	56,043.75	68,500	68,500	53,712.50

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Derivation shown in Table A-11, also see footnotes, Table A-11.

** Assumes wheat price subsidized to $5.00 per bushel.

Table A-12C. Summary -- Price Subsidy Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till*	CBWM No-till, Herb.*	C Conv.	C Chisel	CB No-till
Gross Revenue, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	50,062.50	50,062.50	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	58,812.50	58,812.50	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	56,937.50	56,043.75	68,500	68,500	53,712.50
Total Cost (Net of Land Cost)**											
A uplands	39,665.31	39,094.24	43,020.05	32,853.95	32,600.14	32,285.35	34,479.74	34,203.48	46,405.31	45,834.24	38,885.35
B ridge	41,438.49	40,867.42	44,949.22	33,307.01	33,053.45	32,740.69	34,661.36	34,414.71	48,178.49	47,607.42	39,340.69
C lowlands	42,696.50	42,125.43	45,510.76	34,774.97	34,521.16	34,063.11	35,415.43	35,097.27	49,436.50	48,865.43	40,663.11
Net Return (Excluding Land Costs)											
A uplands	12,834.69	13,405.76	6,854.95	13,458.55	13,712.36	12,152.15	15,582.76	15,859.02	9,594.69	10,165.76	8,552.15
B ridge	23,561.51	24,132.58	20,050.78	25,817.99	26,071.55	25,134.31	24,151.14	24,397.79	20,321.51	20,892.58	21,534.31
C lowlands	22,303.50	22,874.57	6,489.24	24,350.03	24,603.84	16,649.39	21,522.07	20,946.48	19,063.50	19,634.57	13,049.39

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Increased revenue from Table A-11C.

** Derivation shown in Table A-12.

Table A-13C

Net Revenue Ranking -- Price Subsidy Alternative

	Uplands	Ridge	Lowlands		All soils	
high	C BWM-Herb.	CB Chisel	CB Chisel	r	CB Chisel	27,000
	CBWM-Part.	CB Conv.	CB Conv.	r	CB Conv.	
	CB Chisel	CB No-till	C Chisel	r	CB No-till	25,000
	CB Conv.	CBWM-Herb	C Conv.	l	CB Chisel	
	C Chisel	CBWM-Part.	CBWM-Part.	r	CBWM-Herb.	
	C Conv.	C Chisel	CBWM-Herb.	r	C Chisel	
	CB No-till	C Conv.	C Chisel-Ter.	r	C Conv.	23,000
	C Chisel-Ter.	CB No-t.-Ter.	C Conv.-Ter.	l	C Chisel	
	C Conv.-Ter.	C Chisel-Ter.	CB No-till	l	C Conv.	
	CB No-t.-Ter.	C Conv.-Ter.	CB No-t.Ter.	r	CB No-till-Ter.	
low	C No-till	C No-till	C No-till	l	CBWM-Part.	21,000
				l	CBWM-Herb.	
				r	C Conv.-Ter.	
				r	C No-till	20,000
				l	C Chisel-Ter.	
				l	C Conv.-Ter.	
				l	CB No-till	
				u	CBWM-Herb.	
				u	CBWM-Part.	15,000
				u	CB Chisel	
				u	CB Conv.	
				u	C Chisel	
				l	CB No-till.-Ter.	13,000
				u	C. Conv.	
				u	CB No-till	
				u	C Chisel-Ter.	10,000
				u	C Conv.-Ter.	
				u	CB No-till Ter.	8,000
				u	C No-till	
				l	C No-till	6,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

producing CBWM option (on ridge soils) has moved from sixteenth to fifth place. If the results of the Custom Wheat Hay Alternative (A) were combined with a wheat price subsidy (Alternative C) then the CBWM options would become even more attractive financially. It can be concluded, then, that a price subsidy policy could be effective in encouraging the use of cropping patterns which have different water quality impacts than those that would otherwise be used.

Alternative D: Fertilizer Tax

The objective of this alternative is to illustrate the effects of a tax on the use of nitrogen fertilizer. Such a tax policy might be considered to control level of nitrates in public drinking water to meet Federal standards.

In Table A-7D a $.07 tax per pound of nitrogen fertilizer was assumed, raising the cost from $.13 a pound to $.20 a pound. This is a substantial price increase. Comparing "cost of fertilizer per acre" and "total cost of fertilizer" in Table A-7D with the same row in Table A-7, the effect of the tax has been to raise fertilizer expenses by about 35 percent for the option using the most nitrogen fertilizer and by about 15 percent for the option using the least. Table A-10D simply carries through the impact of the increased fertilizer costs from Table A-7D on interest costs (compare with Table A-10).

Table A-12D summarizes the changes due to the fertilizer tax, including increased fertilizer and interest (other) costs. A comparison with Table A-12 shows that net return has been significantly decreased, by $3300 for the options using most nitrogen and by about $800 for the options using least nitrogen. This is a reduction in net return of 50 percent for the continuous corn, no-tillage option on the lowlands.

Table A-13D when compared with Table A-13, Net Revenue Ranking, indicates how the fertilizer tax has shifted the financial return positions of the various farming options. The CBWM options, those using the least amount of nitrogen fertilizer, have moved up in the ranking for the upland soils. The ranking of the continuous corn, no-tillage options,

Table A-7D. Fertilizer Costs -- Fertilizer Tax Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Average Annual Fertilizer amount, lbs/acre*											
N											
A uplands	125	125	137.50	57.50	57.50	63.25	33.75	35.63	125	125	63.25
B ridge	160	160	176	75	75	82.50	42.50	45.25	160	160	82.50
C lowlands	160	160	176	75	75	82.50	42.50	45.25	160	160	82.50
P_2O_5											
A uplands	44	44	44	27.50	27.50	27.50	24.75	24.75	44	44	27.50
B ridge	40	40	40	25	25	25	22.50	22.50	40	40	25
C lowlands	40	40	40	25	25	25	22.50	22.50	40	40	25
K_2O	50	50	50	60	60	60	70	70	50	50	60
Cost of Fertilizer per acre, $**											
A uplands	37.86	37.86	40.36	22.13	22.13	23.28	17.75	18.13	37.86	37.86	23.28
B ridge	44.10	44.10	47.30	25.15	25.15	26.65	19.08	19.63	44.10	44.10	26.65
C lowlands	44.10	44.10	47.30	25.15	25.15	26.65	19.08	19.63	44.10	44.10	26.65
Total Cost of Fertilizer, $											
A uplands	9,465	9,465	10,090	5,532.50	5,532.50	5,820	4,437.50	4,532.50	9,465	9,465	5,820
B ridge	11,025	11,025	11,825	6,287.50	6,287.50	6,662.50	4,770	4,907.50	11,025	11,025	6,662.50
C lowlands	11,025	11,025	11,825	6,287.50	6,287.50	6,662.50	4,770	4,907.50	11,025	11,025	6,662.50
Rental of Application Equipment, $*	262.50	262.50	262.50	131.25	131.25	131.25	153.13	153.13	262.50	262.50	131.25
Total Fertilizer Costs, $											
A uplands	9,727.50	9,727.50	10,352.50	5,663.75	5,663.75	5,951.25	4,590.63	4,685.63	9,727.50	9,727.50	5,951.25
B ridge	11,287.50	11,287.50	12,087.50	6,237.50	6,237.50	6,793.75	4,923.13	5,060.63	11,287.50	11,287.50	6,793.75
C lowlands	11,287.50	11,287.50	12,087.50	6,237.50	6,237.50	6,793.75	4,932.13	5,060.63	11,287.50	11,287.50	6,793.75

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Derivation shown in Table A-7, see footnotes Table A-7.

** Assume prices per lb. are $0.20 for N ($.07 tax), $0.19 for P_2O_5, and $0.09 for K_2O.

Table A-10D. Other Costs -- Fertilizer Tax Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn Drying											
Total Cost*											
A uplands	4,200	4,200	3,990	2,205	2,205	2,205	1,155	1,155	4,480	4,480	2,345
B ridge	5,200	5,200	5,200	2,730	2,730	2,730	1,430	1,430	5,480	5,480	2,870
C lowlands	5,200	5,200	4,160	2,730	2,730	2,457	1,430	1,358.50	5,480	5,480	2,597
Interest on Operating Capital*											
Fertilizer (8 mo.)**											
A uplands	744.15	744.15	791.97	433.28	433.28	455.27	351.18	358.45	744.15	744.15	455.27
B ridge	863.49	863.49	924.69	484.32	484.32	519.72	376.62	387.14	863.49	863.49	591.72
C lowlands	863.49	863.49	924.69	484.32	484.32	519.72	376.62	387.14	863.49	863.49	591.72
Seed (8 mo.)											
A uplands	134.87	134.87	141.67	143.93	143.93	151.16	163.34	160.22	134.87	134.87	151.16
B ridge	148.47	148.47	155.27	150.73	150.73	157.96	166.74	163.62	148.47	148.47	157.96
C lowlands	162.07	162.07	168.87	157.53	157.53	164.76	170.14	167.02	162.07	162.07	164.76
Pésticide (6 mo.)											
A uplands	242.46	242.46	479.61	192.95	192.95	257.66	121.13	148.35	242.46	242.46	257.66
B ridge	222.06	222.06	452.09	165.22	165.22	227.38	106.83	134.06	222.06	222.06	227.38
C lowlands	262.97	262.97	507.03	219.88	219.88	287.25	134.99	162.22	262.97	262.97	287.25
Fuel (3 mo.)	30.32	28.40	23.82	22.82	23.67	19.08	32.05	30.29	30.32	28.40	19.08
Labor (3 mo.)	30.88	27.78	20.37	21.81	23.17	15.77	17.12	14.25	30.88	27.78	15.77
Total Interest											
A uplands	1,182.68	1,177.66	1,457.44	814.79	817	898.94	684.82	711.55	1,182.68	1,177.66	898.94
B ridge	1,295.22	1,290.20	1,576.24	844.90	847.11	939.91	699.36	729.35	1,295.22	1,290.20	939.91
C uplands	1,350.73	1,345.71	1,644.78	912.36	914.57	1,006.58	730.92	760.91	1,350.73	1,345.71	1,006.58
Total Other Costs											
A uplands	5,382.68	5,377.66	5,447.44	3,019.79	3,022	3,103.94	1,839.82	1,866.55	5,662.68	5,657.66	3,243.99
B ridge	6,495.22	6,490.20	6,776.24	3,574.90	3,577.11	3,669.91	2,129.36	2,159.35	6,775.22	6,770.20	3,809.91
C lowlands	6,550.73	6,545.71	5,804.78	3,642.36	3,644.57	3,463.58	2,160.92	2,119.41	6,830.73	6,825.71	3,603.58

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Derivation shown in Table A-10, see footnotes Table A-10.

** Fertilizer costs from Table A-7D.

Table A-12D. Summary — Fertilizer Tax Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Gross Revenue, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	43,031.25	43,031.25	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	51,781.25	51,781.25	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	49,906.25	49,012.50	68,500	68,500	53,712.50
Costs											
Tractor (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64
Implements (excl. fuel)	10,643.65	10,365.66	8,913.07	11,134.31	10,828.87	9,376.28	14,493.38	13,728.36	10,643.65	10,365.66	9,376.28
Fuel	1,426.99	1,336.54	1,120.86	1,073.97	1,113.78	898.10	1,508.40	1,429.91	1,426.99	1,336.54	898.10
Seed											
A uplands	2,380	2,380	2,500	2,540	2,540	2,667.50	2,882.50	2,912.50	2,380	2,380	2,667.50
B ridge	2,620	2,620	2,740	2,660	2,660	2,787.50	2,942.50	2,972.50	2,620	2,620	2,787.50
C lowlands	2,860	2,860	2,980	2,780	2,780	2,907.50	3,002.50	3,032.50	2,860	2,860	2,907.50
Fertilizer*											
A uplands	9,727.50	9,727.50	10,352.50	5,663.75	5,663.75	5,951.25	4,590.63	4,685.63	9,727.50	9,727.50	5,951.25
B ridge	11,287.50	11,287.50	12,087.50	6,237.50	6,237.50	6,793.75	4,923.13	5,060.63	11,287.50	11,287.50	6,793.75
C lowlands	11,287.50	11,287.50	12,087.50	6,237.50	6,237.50	6,793.75	4,923.13	5,060.63	11,287.50	11,287.50	6,793.75
Pesticides											
A uplands	5,705	5,705	11,285	4,540	4,540	6,062.50	2,850.01	3,490.63	5,705	5,705	6,062.50
B ridge	5,225	5,225	10,637.50	3,887.50	3,887.50	5,350	2,513.76	3,154.38	5,225	5,225	5,350
C lowlands	6,187.50	6,187.50	11,930	5,173.75	5,173.75	6,758.75	3,176.25	3,816.88	6,187.50	6,187.50	6,758.75
Labor	2,149.42	2,019.30	1,708.98	1,691.76	1,671.68	1,361.36	2,215.42	2,095.30	2,149.42	2,019.30	1,361.36
Terracing	0	0	0	0	0	0	0	0	6,460	6,460	6,460
Other**											
A uplands	5,382.68	5,377.66	5,447.44	3,019.79	3,022	3,103.94	1,839.82	1,866.55	5,662.68	5,657.66	3,243.94
B ridge	6,495.22	6,490.20	6,776.24	3,574.90	3,577.11	3,669.91	2,129.36	2,159.35	6,775.22	6,770.20	3,809.91
C lowlands	6,550.73	6,545.71	5,804.78	3,642.36	3,644.57	3,463.58	2,160.92	2,119.41	6,830.73	6,825.71	3,603.58
Total Cost (Net of Land Cost)											
A uplands	42,020.15	41,449.40	45,609.04	33,935.84	33,682.03	33,477.57	35,114.87	34,881.29	48,760.15	48,189.08	40.077.57
B ridge	44,452.69	43,881.62	48,264.84	37,531.95	34,278.39	34,293.54	35,496.66	35,272.84	51,192.69	50,621.62	40,943.54
C lowlands	45,710.70	45,139.63	48,826.38	36,005.91	35,752.10	35,615.96	36,214.73	35,955.40	52,450.70	51,879.63	42,215.96
Net Return (Excl. Land Cost)											
A uplands	10,479.85	11,050.60	4,265.96	12,376.66	12,630.47	10,959.93	7,916.38	8,149.96	7,239.85	7,810.92	7,359.93
B ridge	20,547.31	21,118.38	16,735.16	21,593.02	24,846.61	23,581.46	16,284.59	16,508.41	17,307.31	17,878.38	19,931.46
C lowlands	19,289.30	19,860.37	3,173.62	23,119.09	23,372.90	15,096.54	13,691.52	13,057.10	16,049.30	16,620.37	11,496.54

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Fertilizer costs from Table A-7D, **Other costs from Table A-10D.

which use the most nitrogen, is not affected on any of the soil types since the net return for these options was so low in the base case. The rankings of the options with the highest net returns, corn-soybean rotation and continuous corn using chisel and conventional tillage, are not greatly affected by the fertilizer tax even though these options are heavy users of nitrogen. The level of revenue returned to these options is lowered slightly, however. Overall, it can be concluded that not much change has been affected by the tax.

What is found from this comparison is that, in general, nitrogen fertilizer costs are not that great relative to other expenses which the farmer incurs, and therefore a nitrogen fertilizer tax, unless it is extremely large, will not affect net revenue enough to cause a farmer to switch farming practices. Fertilizer costs range from about 12 percent to 20 percent of the total costs that have been calculated for the farming practice options considered. Nitrogen costs make up 30 to 65 percent of total fertilizer costs, depending on the option considered. Since nitrogen fertilizer costs are so small a factor, a tax such as the one considered here will not have a significant impact. If the tax were imposed after an energy cost increase had occurred, however, such as that considered in Alternative B, then a greater impact might be observed.

Unfortunately, the example case is not flexible enough as it stands to account for the most realistic farmer response to a tax such as the one considered in Alternative D. Rather than switch tillage or rotation options in response to net revenue charges, as hypothesized here, a farmer most probably would change his method of nitrogen fertilizer application to increase the use of nitrogen as a side dressing. This response would tend to decrease the amount of nitrogen used while maintaining generally the same rotation and tillage practices.

Table A-13D. Net Revenue Ranking--Fertilizer Tax Alternative

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CB Chisel	r	CB Chisel	← 26,000
	CB Conv.	CB No-till	CB Conv.	l	CB Chisel	
	C Chisel	CB Conv.	C Chisel	l	CB Conv.	← 24,000
	CB No-till	C Chisel	C Conv.	r	CB No-till	
	C Conv.	C Conv.	C Chisel-Ter.	r	CB Conv.	
	CBWM-Herb.	CB No-t.-Ter.	C Conv.-Ter.	r	C Chisel	
	CBWM-Part.	C Chisel-Ter.	CB No-till	r	C Conv.	← 20,000
	C Chisel-Ter.	C Conv.-Ter.	CBWM-Part.	r	CB No-t.-Ter.	
	CB No-t.-Ter.	C No-till	CBWM-Herb.	l	C Chisel	
	C Conv.-Ter.	CBWM-Herb.	CB No-t.-Ter.	l	C Conv.	← 19,000
low	C No-till	CBWM-Part.	C No-till	r	C Chisel-Ter.	
				r	C Conv.-Ter.	← 17,000
				r	C No-till	
				l	C Chisel-Ter.	
				r	CBWM-Herb.	
				r	CBWM-Part.	
				l	C Conv.-Ter	
				l	CB No-till	
				l	CBWM-Part.	
				l	CBWM-Herb.	← 13,000
				u	CB Chisel	
				u	CB Conv.	
				l	CB No-t.-Ter.	
				u	C Chisel	← 11,000
				u	CB no-till	
				u	C Conv.	
				u	CBWM-Herb.	← 8,000
				u	CBWM-Part.	
				u	C Chisel-Ter.	
				u	CB No-t.-Ter.	
				u	C Conv.-Ter.	← 7,000
				u	C No-till	
				l	C No-till	← 3,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

Alternative E: Insecticide Scouting

This alternative is based on the premise that the amount of insecticides used on corn can be reduced by scouting to determine areas with high potential soil insect problems and by treating only those fields that need treatment with the full recommended dosage. Other areas would not be treated for these pests. Alternative E shows the effects on net revenue of such a reduced pesticide program on a typical farm in the case study area.

Table A-8E gives pesticide costs under the scouting alternative. Insecticide costs per acre for corn are determined in the same manner as for Table A-8. The number of acres treated are based on approximate percentages (listed in the footnote to Table A-8E) that might apply to a typical farm on the soils and for the crop rotations under consideration. Scouting costs are based on an assumed $2.00 per acre cost for the number of acres that would typically need scouting for the soil types being considered. The lowlands, for example, are wetter and therefore more likely to harbor certain insects. Herbicides applied to corn are not affected by the scouting option, nor are soybean pesticide costs since no insecticides were applied to soybeans in the base case. The comparison of "Total Pesticide Cost" in Table 8E with that in Table A-8 shows that the scouting option has reduced pesticide costs by anywhere from $800 to $2,250 and 12 to 40 percent depending on the farming practice used.

Table A-10E shows slightly reduced interest costs compared to Table A-10 in response to the reduced pesticide costs under the scouting alternative. The reduced pesticide and interest costs are summarized in Table A-12E along with other costs which are the same as for the base case. Note that

Table A-8E. Pesticide Costs -- Insectivide Scouting Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn, Cost											
Herbicide, $/acre*											
A uplands	13.51	13.51	26.78	13.51	13.51	24.50	13.51	23.76	13.51	13.51	24.50
B ridge	11.59	11.59	24.19	11.59	11.59	22.26	11.59	21.84	11.59	11.59	22.26
C lowlands	15.44	15.44	29.36	15.44	15.44	26.78	15.44	25.69	15.44	15.44	26.78
Acres	250	250	250	125	125	125	62.5	62.5	250	250	125
Herbicide Cost, $											
A uplands	3,377.50	3,377.50	6,695	1,688.75	1,688.75	3,062.50	844.38	1,485	3,377.50	3,377.50	3,062.50
B ridge	2,897.50	2,897.50	6,047.50	1,448.75	1,448.75	2,782.50	724.38	1,365	2,897.50	2,897.50	2,782.50
C lowlands	3,860	3,860	7,340	1,930	1,930	3,347.50	965	1,605.63	3,860	3,860	3,347.50
Insecticide, $/acre*	9.31	9.31	18.36	9.05	9.05	9.05	17.14	17.14	9.31	9.31	9.05
Acres treated**											
A uplands	100	100	100	1.25	1.25	1.25	0.63	0.63	100	100	1.25
B ridge	100	100	100	1.25	1.25	1.25	0.63	0.63	100	100	1.25
C lowlands	100	100	100	6.25	6.25	6.25	4.69	4.69	100	100	6.25
Insecticide cost, $											
A uplands	931	931	1,836	11.31	11.31	11.31	10.80	10.80	931	931	11.31
B ridge	931	931	1,836	11.31	11.31	11.31	10.80	10.80	931	931	11.31
C lowlands	931	931	1,836	56.56	56.56	56.56	80.39	80.39	931	931	56.56
Scouting Cost/acre, $	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Acres Scouted											
A uplands	250	250	250	25	25	25	12.50	12.50	250	250	25
B ridge	250	250	250	25	25	25	12.50	12.50	250	250	25
C lowlands	250	250	250	125	125	125	31.25	31.25	250	250	125
Total Scouting Cost, $											
A uplands	500	500	500	50	50	50	25	25	500	500	50
B ridge	500	500	500	50	50	50	25	25	500	500	50
C lowlands	500	500	500	250	250	250	62.50	62.50	500	500	250
Total Cost, $											
A uplands	4,808.50	4,808.50	9,031	1,750.06	1,750.06	3,123.81	880.18	1,520.80	4,808.50	4,808.50	3,123.81
B ridge	4,328.50	4,328.50	8,383.50	1,510.06	1,510.06	2,843.81	760.18	1,400.80	4,328.50	4,328.50	2,843.81
C lowlands	5,291	5,291	9,676	2,236.56	2,236.56	3,654.06	1,107.89	1.748.52	5,291	5,291	3,654.06
Soybeans, Cost											
Total Cost, $*											
A uplands				1,720	1,720	1,868.75	934.38	934.38			1,868.75
B ridge				1,307.50	1,307.50	1,436.25	718.13	718.13			1,436.25
C lowlands				2,112.50	2,112.50	2,280	1,140	1,140			2,280
Total Pesticide Cost, $											
A uplands	4,808.50	4,808.50	9,031	3,470.06	3,470.06	4,992.56	1,814.56	2,455.18	4,808.50	4,808.50	4,992.56
B ridge	4,328.50	4,328.50	8,383.50	2,817.56	2,817.56	4,280.06	1,478.31	2,118.93	4,328.50	4,328.50	4,280.06
C lowlands	5,291	5,291	9,676	4,349.06	4,349.06	5,934.06	2,247.89	2,888.52	5,291	5,291	5,934.06

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* See Table A-8 for derivation; see footnotes, Table A-8.

** Assumes 40% continuous corn treated; 7.5% lowlands CB and CBWM treated; 1% uplands, ridge CB and CBWM treated, based upon discussions with Dr. Thomas Turpin, Purdue University and on Turpin, F. T., "Insect Insurance: Potential Management Tool for Corn Insects," in Bulletin of the Entomological Society of America, Vol. 23, No. 3, pp. 181-184, September 1977.

Table A-10E. Other Costs — Insecticide Scouting Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn Drying											
Total Cost*											
A uplands	4,200	4,200	3,990	2,205	2,205	2,205	1,155	1,155	4,480	4,480	2,345
B ridge	5,200	5,200	5,200	2,730	2,730	2,730	1,430	1,430	5,480	5,480	2,870
C lowlands	5,200	5,200	4,160	2,730	2,730	2,457	1,430	1,358.50	5,480	5,480	2,597
Interest on Operating Capital*											
Fertilizer (8 mo.)											
A uplands	576.81	576.81	607.98	356.39	356.39	370.55	306.05	310.64	576.81	576.81	370.55
B ridge	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
C lowlands	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
Seed (8 mo.)											
A uplands	134.87	134.87	141.67	143.93	143.93	151.16	163.34	160.22	134.87	134.87	151.16
B ridge	148.47	148.47	155.27	150.73	150.73	157.96	166.74	163.62	148.47	148.47	157.96
C lowlands	162.07	162.07	168.87	157.53	157.53	164.76	170.14	167.02	162.07	162.07	164.76
Pesticide (6 mo.)**											
A uplands	204.36	204.36	383.82	147.48	147.48	212.18	77.12	104.35	204.36	204.36	212.18
B ridge	183.96	183.96	356.30	119.74	119.74	181.90	62.83	90.05	183.96	183.96	181.90
C lowlands	224.87	224.87	411.23	184.84	184.84	252.20	95.54	122.76	224.87	224.87	252.20
Fuel (3 mo.)	30.32	28.40	23.82	22.82	23.67	19.08	32.05	30.28	30.32	28.40	19.08
Labor (3 mo.)	30.88	27.78	20.37	21.81	23.17	15.77	17.12	14.25	30.88	27.78	15.77
Total Interest											
A uplands	977.24	972.22	1,177.66	692.43	694.64	768.74	595.68	619.74	977.24	972.22	768.74
B ridge	1,042.92	1,037.90	1,244.83	705.73	707.94	784.08	598.56	624.71	1,042.92	1,037.90	784.08
C lowlands	1,098.43	1,093.41	1,313.36	777.63	779.84	861.18	634.67	660.82	1,098.43	1,093.41	861.18
Total Other Costs											
A uplands	5,177.24	5,172.22	5,167.66	2,897.43	2,899.64	2,973.73	1,750.68	1,774.74	5,457.24	5,452.22	3,113.74
B ridge	6,242.92	6,237.91	6,444.83	3,435.73	3,437.94	3,514.08	2,028.56	2,054.71	6,522.92	6,517.90	3,654.08
C lowlands	6,298.53	6,293.41	5,473.36	3,507.63	3,509.84	3,318.18	2,064.67	2,019.32	6,578.43	6,573.41	3,458.18

Notes: C = corn-bean; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

*Derivation shown in Table A-10. See footnotes Table A-10, **Pesticide costs from Table A-8E.

Table A-12E. Summary — Insecticide Scouting Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Gross Revenue, $											
A uplands	52,500	52,500	49,875	46,312.50	46,312.50	44,437.50	43,031.25	43,031.25	56,000	56,000	47,437.50
B ridge	65,000	65,000	65,000	59,125	59,125	57,875	51,781.25	51,781.25	68,500	68,500	60,875
C lowlands	65,000	65,000	52,000	59,125	59,125	50,712.50	49,906.25	49,012.50	68,500	68,500	53,712.50
Costs											
Tractor (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64
Implements (excl. fuel)	10,643.65	10,365.66	8,913.07	11,134.31	10,828.87	9,376.28	14,493.38	13,728.36	10,643.65	10,365.66	9,376.28
Fuel	1,426.99	1,336.54	1,120.86	1,073.97	1,113.78	898.10	1,508.40	1,429.91	1,426.99	1,336.54	898.10
Seed											
A uplands	2,380	2,380	2,500	2,540	2,540	2,667.50	2,882.50	2,912.50	2,380	2,380	2,667.50
B ridge	2,620	2,620	2,740	2,660	2,660	2,787.50	2,942.50	2,972.50	2,620	2,620	2,787.50
C lowlands	2,860	2,860	2,980	2,780	2,780	2,907.50	3,002.50	3,032.50	2,860	2,860	2,907.50
Fertilizer											
A uplands	7,540	7,540	7,947.50	4,658.75	4,658.75	4,843.75	4,000.63	4,060.63	7,540	7,540	4,843.75
B ridge	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8,487.50	5,351.25
C lowlands	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8.487.50	5.351.25
Pesticides*											
A uplands	4,808.50	4,808.50	9,031	3,470.06	3,470.06	4,992.56	1,814.56	2,455.18	4,808.50	4,808.50	4,992.56
B ridge	4,328.50	4,328.50	8,383.50	2,817.56	2,817.56	4,280.06	1,478.31	2,118.93	4,308.50	4,328.50	4,280.06
C lowlands	5,291	5,291	9,676	4,349.06	4,349.06	5,934.06	2,247.89	2,888.52	5,291	5,291	5,934.06
Labor	2,149.42	2,019.30	1,708.98	1,691.76	1,671.68	1,361.36	2,215.42	2,095.30	2,149.42	2,019.30	1,361.36
Terracing	0	0	0	0	0	0	0	0	6,460	6,460	6,460
Other**											
A uplands	5,177.24	5,172.22	5,167.66	2,897.43	2,899.64	2,973.73	1,750.68	1,774.74	5,457.24	5,452.22	3,113.74
B ridge	6,242.92	6,237.91	6,444.83	3,435.73	3,437.94	3,514.08	2,028.56	2,054.71	6,522.92	6,517.90	3,654.08
C lowlands	6,298.53	6,293.41	5,473.36	3,507.63	3,509.84	3,318.18	2,064.67	2,019.32	6,578.43	6,573.41	3,458.18
Total Cost (Net of Land Cost)											
A uplands	38,790.71	38,159.64	40,670.26	31,738.54	31,484.73	31,169.92	33,400.28	33,129.03	45,470.89	44,899.64	37,769.87
B ridge	40,503.89	39,933.05	42,599.43	32,191.59	31,938.03	31,625.27	33,581.91	33,340.25	47,243.89	46,672.82	38,225.27
C lowlands	41,762	41,190.83	43,160.97	33,915.24	33,661.43	33,203.37	34,447.62	34,134.45	48,501.90	47,930.83	39,803.37
Net Return (Excl. Land Cost)											
A uplands	13,769.29	14,340.36	9,204.74	14,573.96	14,827.77	13,267.58	9,630.97	9,902.22	10,529.11	11,100.36	9,667.63
B ridge	24,496.11	25,067.17	22,400.57	26,933.41	27,186.97	26,249.73	18,199.34	18,441.00	21,256.11	21,827.18	22,649.73
C lowlands	23,238	23,809.17	8,839.03	25,209.76	25,463.57	17,509.13	15,458.63	14,873.05	19,998.10	20,569.17	13,909.13

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

Pesticide costs from Table A-8E, **Other costs from Table A-10E.

gross revenue in Table A-12E is the same as in Table A-12; the scouting and selected treatment with the recommended insecticide dosage has insured that there is no yield loss under this alternative. Net returns have been increased slightly, approximately $1,000 for all options except the continuous corn no-tillage options for which revenue increased by $2,350.

Table A-13E shows the net revenue ranking of the farming practice options under the scouting alternative. When compared with Table A-13, it can be seen that the revenue changes caused by reducing insecticide use through scouting are not significant enough to cause many changes in ranking of the options. When each soil type is considered separately the only ranking change which occurs is the movement of the continuous corn no-tillage option from ninth to seventh place on the ridge soils. When all soils are considered together the only change is that net revenue increases slightly and the continuous corn no-tillage option on the ridge soil moves up two places. The revenue for the two continuous corn no-tillage options on the uplands and lowlands has been significantly increased as shown by the lower net revenue bound change from $6,000 in Table A-13 to $8,000 in Table A-13E. The relative net return of these two options is so low in the base case, however, that their ranking is not affected by the revenue increase. The three continuous corn no-tillage options are most affected by the pesticide scouting alternative because in the base case they require the most insecticide; for the other options, insecticide costs are not high enough relative to other production inputs for financial returns to be significantly altered by their reduction. Pesticide costs account for 8 to 26 percent of total costs, depending on the farming practice used and insecticide costs are 30 to 40 percent of pesticide costs. More interesting results might be gained by applying the scouting option to the increased energy cost scenario where it might serve to reduce a very expensive input.

Table A-13E. Net Revenue Ranking--Insecticide Scouting Alternative

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CB Chisel	r	CB Chisel	← 28,000
	CB Conv.	CB Conv.	CB Conv.	r	CB Conv.	
	C Chisel	CB No-till	C Chisel	r	CB No-till	← 26,000
	C Conv.	C Chisel	C Conv.	l	CB Chisel	
	CB No-till	C Conv.	C Chisel-Ter.	l	CB Conv.	
	C Chisel-Ter.	CB No-t.-Ter.	C Conv.-Ter.	r	C Chisel	
	C Conv.-Ter.	C No-till	CB No-till	r	C Conv.	
	CBWM-Herb.	C Chisel-Ter.	CBWM-Part.	l	C Chisel	← 24,000
	CB No-t.-Ter.	C Conv.-Ter.	CBWM-Herb.	l	C Conv.	
	CBWM-Part.	CBWM-Herb.	CB No-t.-Ter.	r	CB No-till-Ter.	
low	C No-till	CBWM-Part	C No-till	r	C No-till	
				r	C Chisel Ter.	← 22,000
				r	C Conv.-Ter.	
				r	C Conv.-Ter.	
				l	C Chisel-Ter.	
				l	C Conv.-Ter.	
				r	CBWM-Herb.	← 20,000
				r	CBWM-Part.	
				l	CB No-till	
				l	CBWM-Part.	← 17,000
				l	CBWM-Herb.	
				u	CB Chisel	
				u	CB Conv.	
				u	C Chisel	
				l	CB No-till-Ter.	← 14,000
				u	C Conv.	
				u	CB No-till	
				u	C Chisel-Ter.	← 13,000
				u	C Conv.-Ter.	
				u	CBWM-Herb.	← 10,000
				u	C CB No-till-Ter.	
				u	CBWM-Part.	
				u	C No-till	← 9,000
				l	C No-till	← 8,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

Alternative F: No Insecticide Treatment

This alternative is the extreme end of the variation examined in Alternative E. In this case no insecticide treatments are used for any of the options. Table A-8F shows that pesticide costs have been reduced by the elimination of insecticide costs; only herbicide costs remain. Total pesticide costs have been decreased by approximately $1,000 to $4,500 or by 30 to 45 percent depending on the farming practice (compare with Table A-8).

In Table A-10F these reduced pesticide costs are translated into correspondingly reduced interest costs. Corn drying costs are also reduced since yield loss occurs as a result of insect damage. Table A-11F shows the change in yield due to this loss caused by lack of insecticide treatment. Losses differ according to soil types and crop rotations used and are detailed in a footnote to Table A-11F. Crop loss, of course, reduces gross revenue. Comparing Table A-11F to Table A-11, it can be seen that gross revenue is reduced significantly for the continuous corn options ($2,000) but only slightly for the other options ($5 to $50).

Table A-12F summarizes the effects of reduced gross revenue and reduced pesticide costs. Net returns for all options have been increased slightly compared to the base case (Table A-12): about $600 for the continuous corn chisel and conventionally tilled options; approximately $3,000 for the continuous corn no-tillage options; and about $1,000 for all other options.

The net revenue ranking of all options under this alternative is shown in Table A-13F. As was true for Alternative E, there are relatively

Table A-8F. Pesticide Costs -- No Insecticide Treatment Alternative

Item	Tillage Practices			Rotations					Terraces		
	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn, Cost											
Herbicide, $/acre*											
A uplands	13.51	13.51	26.78	13.51	13.51	24.50	13.51	23.76	13.51	13.51	24.50
B ridge	11.59	11.59	24.19	11.59	11.59	22.26	11.59	21.84	11.59	11.59	22.26
C lowlands	15.44	15.44	29.36	15.44	15.44	26.78	15.44	25.69	15.44	15.44	26.78
Acres	250	250	250	125	125	125	62.5	62.5	250	250	125
Total Cost, $											
A uplands	3,377.50	3,377.50	6,695	1,688.75	1,688.75	3,062.50	844.38	1,485	3,377.50	3,377.50	3,062.50
B ridge	2,897.50	2,897.50	6,047.50	1,448.75	1,448.75	2,782.50	724.38	1,365	2,897.50	2,897.50	2,782.50
C lowlands	3,860	3,860	7,340	1,930	1,930	3,347.50	965	1,650.63	3,860	3,860	3,347.50
Soybeans, Cost											
Total Cost, $*											
A uplands				1,720	1,720	1,868.75	934.38	934.38			1,868.75
B ridge				1,307.50	1,307.50	1,436.25	718.13	718.13			1,436.25
C lowlands				2,112.50	2,112.50	2,280	1,140	1,140			2,280
Total Pesticide Cost, $											
A uplands	3,377.50	3,377.50	6,695	3,408.75	3,408.75	4,931.25	1,778.76	2,419.33	3,377.50	3,377.50	4,931.25
B ridge	2,897.50	2,897.50	6,047.50	2,756.25	2,756.25	4,218.75	1,442.51	2,083.13	2,897.50	2,897.50	4,218.75
C lowlands	3,860	3,860	7,340	4,042.50	4,042.50	5,627.50	2,105	2,745.64	3,860	3,860	5,627.50

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* See Table A-8 for derivation; see footnotes Table A-8.

Table A-10F. Other Costs — No Insecticide Treatment Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn Drying											
Grain harvested, bu.*											
A uplands	25,250	25,250	23,937.50	13,775.62	13,775.62	13,775.62	7,215.94	7,215.94	27,000	27,000	14,650.62
B ridge	31,500	31,500	31,500	17,056.87	17,056.87	17,056.87	8,934.69	8,934.69	33,250	33,250	17,931.87
C lowlands	31,500	31,500	25,000	17,034.37	17,034.37	15,328.12	8,916.41	8,469.54	33,250	33,250	16,203.12
Cost per bu., $**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Total Cost											
A uplands	4,040	4,040	3,830	2,204.10	2,204.10	2,204.10	1,154.55	1,154.55	4,320	4,320	2,344.10
B ridge	5,040	5,040	5,020	2,729.10	2,729.10	2,729.10	1,429.55	1,429.55	5,320	5,320	2,869.10
C lowlands	5,040	5,040	4,000	2,725.50	2,725.50	2,452.50	1,426.63	1,355.13	5,320	5,320	2,592.50
Interest on Operating Capital**											
Fertilizer (8 mo.)											
A uplands	576.81	576.81	607.98	356.39	356.39	370.55	306.05	310.64	576.81	576.81	370.55
B ridge	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
C lowlands	649.29	649.29	689.07	390.63	390.63	409.37	319.82	326.51	649.29	649.29	409.37
Seed (8 mo.)											
A uplands	134.87	134.87	141.67	143.93	143.93	151.16	163.34	160.22	134.87	134.87	151.16
B ridge	148.47	148.47	155.27	150.73	150.73	157.96	166.74	163.62	148.47	148.47	157.96
C lowlands	162.07	162.07	168.87	157.53	157.73	164.76	170.14	167.02	162.07	162.07	164.76
Pesticide (6 mo.)***											
A uplands	143.54	143.54	284.54	144.87	144.87	209.58	75.60	102.82	143.54	143.54	209.58
B ridge	123.14	123.14	257.02	117.14	117.14	179.30	61.31	88.53	123.14	123.14	179.30
C lowlands	164.05	164.05	311.95	171.81	171.81	239.17	89.46	116.69	164.05	164.05	239.17
Fuel (3 mo.)	30.32	28.40	23.82	22.82	23.67	19.08	32.05	30.28	30.32	28.40	19.00
Labor (3 mo.)	30.88	27.78	20.37	21.81	23.17	15.77	17.12	14.25	30.88	27.78	15.77
Total Interest											
A uplands	916.42	911.40	1,078.38	689.82	692.03	766.14	594.16	618.21	916.42	911.40	766.14
B ridge	982.10	977.08	1,145.55	703.13	705.34	781.48	597.04	623.19	982.10	977.08	781.48
C lowlands	1,081.02	1,032.59	1,214.08	764.60	766.81	848.15	628.59	654.75	1,037.61	1,032.59	848.15
Total Other Costs											
A uplands	4,956.42	4,951.40	4,908.38	2,893.92	2,896.13	2,970.24	1,748.71	1,772.76	5,236.42	5,231.40	3,110.24
B ridge	6,022.10	6,017.08	6,185.55	3,432.23	3,434.44	3,510.58	2,026.59	2,052.74	6,302.10	6,297.08	3,650.58
C lowlands	6,077.61	6,072.59	5,214.08	3,490.10	3,492.31	3,300.65	2,055.22	2,009.88	6,357.61	6,352.59	3,440.65

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* From Table A-11F, **See footnotes Table A-10, ***From Table A-8F.

Table A-11F. Revenue -- No Insecticide Treatment Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Corn											
Expected yield, bu/acre **											
A uplands	105	105	99.75	110.25	110.25	110.25	115.50	115.50	112	112	117.25
B ridge	130	130	130	136.50	136.50	136.50	143	143	137	137	143.50
C lowlands	130	130	104	136.50	136.50	122.85	143	143	137	137	129.85
Area cropped, acres	250	250	250	125	125	125	62.50	62.50	250	250	125
Loss*											
A uplands	1,000	1,000	1,000	5.63	5.63	5.63	2.81	2.81	1,000	1,000	5.63
B ridge	1,000	1,000	1,000	5.63	5.63	5.63	2.81	2.81	1,000	1,000	5.63
C lowlands	1,000	1,000	1,000	28.13	28.13	28.13	21.09	21.09	1,000	1,000	28.13
Total output, bu.											
A uplands	25,250	25,250	23,937.50	13,775.62	13,775.62	13,775.62	7,215.94	7,215.94	27,000	27,000	14,650.62
B ridge	31,500	31,500	31,500	17,056.87	17,056.87	17,056.87	8,934.69	8,934.69	33,250	33,250	17,931.87
C lowlands	31,500	31,500	25,000	17,034.37	17,034.37	15,328.12	8,916.41	8,469.54	33,250	33,250	16,203.12
Expected price/ $/bu.**	2	2	2	2	2	2	2	2	2	2	2
Gross Revenue, $											
A uplands	50,500	50,500	47,875	27,551.24	27,551.24	27,551.24	14,431.88	14,431.88	54,000	54,000	14,644.99
B ridge	63,000	63,000	63,000	34,113.74	34,113.74	34,113.74	17,869.38	17,869.38	66,500	66,500	17,926.24
C lowlands	63,000	63,000	50,000	34,068.74	34,068.74	30,656.24	17,832.82	16,939.08	66,500	66,500	32,406.24
Soybeans											
Gross Revenue, $**											
A uplands				18,750	18,750	16,875	8,437.50	8,437.50			18,125
B ridge				25,000	25,000	23,750	11,875	11,875			25,000
C lowlands				25,000	22,500	20,000	10,000	10,000			21,250
Wheat											
Gross Revenue, $**							7,031.25	7,031.25			
Hay											
Gross Revenue, $**											
A uplands							13,215	13,215			
B ridge							15,000	15,000			
C lowlands							15,000	15,000			
TOTAL GROSS REVENUE, $											
A uplands	50,500	50,500	47,875	46,301.24	46,301.24	44,426.24	43,025.63	43,025.63	54,000	54,000	47,426.24
B ridge	63,000	63,000	63,000	59,113.74	59,113.74	57,863.74	51,775.63	51,775.63	66,500	66,500	60,863.74
C lowlands	63,000	63,000	50,000	59,068.74	59,068.74	50,656.24	49,864.07	48,970.32	66,500	66,500	53,656.24

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

* Loss due to lack of insecticide treatment. Assume 10 bu/acre loss on 40% of acreage for continuous corn. For CB and CBWM, assume 4.5 bu/acre loss on 5% and 7.5%, respectively, of corn acreage for the lowlands. Assume 4.5 bu/acre loss on 1% of acreage for CB and CBWM on the uplands and ridge. Assumptions based upon discussions with Dr. Thomas Turpin, Purdue University and on Turpin, F. T., "Insecticide Insurance, Potential Management Tool for Corn Insects," in Bulletin of the Entomological Society of America, Vol. 23, No. 3, pp. 181-184, September 1977.

** For derivation see Table A-11; see footnotes, Table A-11.

Table A-12F. Summary — No Insecticide Treatment Alternative

	Tillage Practices			Rotations					Terraces		
Item	C Conv.	C Chisel	C No-till	CB Conv.	CB Chisel	CB No-till	CBWM Part. No-till	CBWM No-till, Herb.	C Conv.	C Chisel	CB No-till
Gross Revenue, $*											
A uplands	50,500	50,500	47,875	46,301.24	46,301.24	44,426.24	43,025.63	43,025.63	54,000	54,000	47,426.24
B ridge	63,000	63,000	63,000	59,113.74	59,113.74	57,863.74	51,775.63	51,775.63	66,500	66,500	60,853.74
C uplands	63,000	63,000	50,000	59,068.74	59,068.74	50,656.24	49,864.07	48,970.32	66,500	66,500	53,656.24
Costs											
Tractor (excl. fuel)	4,604.91	4,537.42	4,281.19	4,272.26	4,301.95	4,056.64	4,734.71	4,672.41	4,604.91	4,537.42	4,056.64
Implements (excl. fuel)	10,643.65	10,365.66	8,913.07	11,134.31	10,828.87	9,376.28	14,493.38	13,728.36	10,643.65	10,365.66	9,376.28
Fuel	1,426.99	1,336.54	1,120.86	1,073.97	1,113.78	898.10	1,508.40	1,429.40	1,426.99	1,336.54	898.10
Seed											
A uplands	2,380	2,380	2,500	2,540	2,540	2,667.50	2,882.50	2,912.50	2,380	2,380	2,667.50
B ridge	2,620	2,620	2,740	2,660	2,660	2,787.50	2,942.50	2,972.50	2,620	2,620	2,787.50
C lowlands	2,860	2,860	2,980	2,780	2,780	2,907.50	3,002.50	3,032.50	2,860	2,860	2,907.50
Fertilizer											
A uplands	7,540	7,540	7,947.50	4,658.75	4,658.75	4,843.75	4,000.63	4,060.63	7,540	7,540	4,843.75
B ridge	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8,487.50	5,351.25
C lowlands	8,487.50	8,487.50	9,007.50	5,106.25	5,106.25	5,351.25	4,180.63	4,268.13	8,487.50	8,487.50	5,351.25
Pesticides**											
A uplands	3,377.50	3,377.50	6,695	3,408.75	3,408.75	4,931.25	1,778.76	2,419.33	3,377.50	3,377.50	4,931.25
B ridge	2,897.50	2,897.50	6,047.50	2,756.25	2,756.25	4,218.75	1,442.51	2,083.13	2,897.50	2,897.50	4,218.75
C lowlands	3,860	3,860	7,340	4,042.50	4,042.50	5,627.50	2,105	2,745.63	3,860	3,860	5,627.50
Labor	2,149.42	2,019.30	1,708.98	1,691.76	1,671.68	1,361.36	2,215.42	2,095.30	2,149.42	2,019.30	1,361.36
Terracing	0	0	0	0	0	0	0	0	6,460	6,460	6,460
Other***											
A uplands	4,956.42	4,951.40	4,908.38	2,893.92	2,896.13	2,970.24	1,748.71	1,772.76	5,236.42	5,231.40	3,110.24
B ridge	6,022.10	6,017.08	6,185.55	3,432.23	3,434.44	3,510.58	2,026.59	2,052.74	6,302.10	6,297.08	3,650.58
C lowlands	6,077.61	6,072.59	5,214.08	3,490.10	3,492.31	3,300.65	2,055.22	2,009.88	6,357.61	6,352.59	3,440.65
Total Cost (Net of Land Cost)											
A uplands	37,078.89	36,507.82	38,074.98	31,673.72	31,419.91	31,105.12	33,362.51	33,019.25	43,818.89	43,247.82	37,705.12
B ridge	38,852.07	38,281	40,004.15	32,126.78	31,873.22	31,560.46	33,544.14	33,302.48	45,592.07	45,021	38,160.46
C lowlands	40,110.08	39,539.01	40,565.69	33,591.15	33,337.34	32,906.28	34,295.28	33,982.12	46,850.08	46,279.01	39,479.28
Net Return (Excl. Land Costs)											
A uplands	13,421.11	13,992.18	9,800.02	14,627.52	14,881.33	13,321.12	9,663.12	9,934.38	10,181.11	10,752.18	9,721.12
B ridge	24,147.93	24,719	22,995.85	26,986.96	27,240.52	26,303.28	18,231.49	18,473.15	20,907.93	21,479	22,693.28
C lowlands	22,889.92	23,460.99	9,434.31	25,477.59	25,731.40	17,749.96	15,568.79	14,988.20	19,649.92	20,220.99	14,176.96

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

*From Table A-11F, **From Table A-8F, ***From Table A-10F.

Table A-13F

Net Revenue Ranking -- No Insecticide Treatment Alternative

	Uplands	Ridge	Lowlands		All Soils	
high	CB Chisel	CB Chisel	CH Chisel	r	CB Chisel	← 28,000
	CB Conv.	CB Conv.	CB Conv.	r	CB Conv.	
	C Chisel	CB No-till	C Chisel	r	CB No-till	← 26,000
	C Conv.	C Chisel	C Conv.	l	CB Chisel	
	CB No-till	C Conv.	C Chisel-Ter.	l	CB Conv.	
	C Chisel-Ter.	C No-till	C Conv.-Ter.	r	C Chisel	
	C Conv.-Ter.	CB No-t.-Ter.	CB No-till	r	C Conv.	← 24,000
	CBWM-Herb.	C Chisel-Ter.	CBWM-Part.	l	C Chisel	
	C No-till	C Conv.-Ter.	CBWM-Herb.	r	C No-till	
	CB No-t.-Ter.	CBWM-Herb.	CB No-t.-Ter.	l	C Conv.	
low	CBWM-Part.	CBWM-Part.	C No-till	r	CB No-till-Ter.	
				r	C Chisel-Ter.	← 21,000
				r	C Conv.-Ter.	
				l	C Chisel-Ter.	
				l	C Conv.-Ter.	← 19,000
				r	CBWM-Herb.	
				r	CBWM-Part.	
				l	CB No-till	← 17,000
				l	CBWM-Part	
				l	CBWM-Herb.	
				u	CB Chisel	
				u	CB Conv.	
				l	CB No-till-Ter.	← 14,000
				u	C Chisel	
				u	C Conv.	
				u	CB No-till	← 13,000
				u	C Chisel-Ter.	
				u	C Conv.-Ter.	← 10,000
				u	CBWM-Herb.	
				u	C No-till	
				CB	No-till-Ter.	
				u	CBWM-Part.	
				l	C No-till	← 9,000

Notes: C = corn; CB = corn-bean; CBWM = corn-bean-wheat-meadow.

r = ridge; l = lowlands; u = uplands.

few shifts in financial return position as a result of eliminating insecticide treatment altogether. The continuous corn no-tillage options on the ridge and uplands moved up in the ranking because they bear the heaviest pesticide costs in the base case and this alternative relieved this burden somewhat. Net revenue improves for all options and particularly for the continuous corn no-tillage options, one of which remains at the bottom of the ranking, however. Other shifts in position that occur when all soils are ranked together are a result of slight differences in gain or loss from the decreased revenue and decreased pesticide costs and are not especially significant.

The same conclusions can be drawn from this alternative as from Alternative E, namely, that insecticide costs are not significant relative to other productions costs and therefore even total elimination of these costs (which account for at most 10 percent of total costs) will not affect the farmer's choice of farming practice. This is true even though there is a reduction in yield caused by the lack of pesticide use; the decreased pesticide costs more than make up for the lost revenue. As with Alternative E, it might be worthwhile to combine the no insecticide treatment alternative with other alternatives that have been considered such as the increased energy scenario.

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Appendix B

Methods for Predicting Watershed Loadings

Introduction

The methods described below have been developed to assess the impacts of agricultural practices on nonpoint pollutant loadings. The models are of an empirical nature and are concerned with long-term average emissions, in the spirit of the Universal Soil Loss Equation (Wischmeier and Smith, 1972). Average export rates of the following substances are evaluated in surface runoff and in subsurface drainage:

1) Sediment (sand, silt, and clay fractions);
2) Phosphorus (extractable particulate and soluble);
3) Soluble nitrogen; and
4) Dissolved color.

The computed concentrations of these components are assumed to be representative of average water quality conditions in rivers draining the agricultural watersheds. The methodology is appropriate for linking with downstream models for the purpose of evaluating quality impacts in impounded waters, as discussed in a subsequent section (see Methods for Predicting Impoundment Water Quality).

Using the generalized pathways depicted in Figure B-1, emissions are computed as functions of the following characteristics:

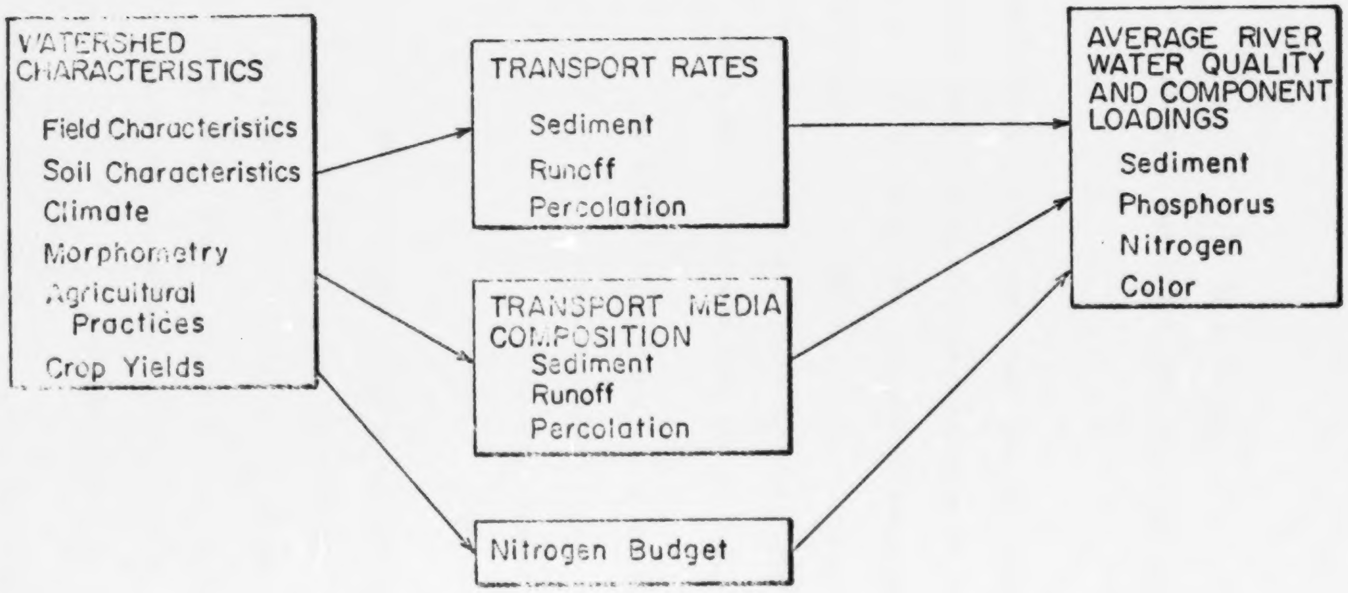
WATERSHED CHARACTERISTICS
Field Characteristics
Soil Characteristics
Climate
Morphometry
Agricultural Practices
Crop Yields
TRANSPORT RATES
Sediment
Runoff
Percolation
TRANSPORT MEDIA COMPOSITION
Sediment
Runoff
Percolation
Nitrogen Budget
AVERAGE RIVER WATER QUALITY AND COMPONENT LOADINGS
Sediment
Phosphorus
Nitrogen
Color

Figure B-1. Pathways in Predicting Watershed Loadings

1) Surface Soil Properties
    a) Erodibility (K factor in USLE, Wischmeier and Smith, 1972);
    b) Texture (sand, silt, and clay content);
    c) Hydrologic Soil Group (SCS/USDA, 1971);
    d) Extractable phosphorus content (in each texture class);
    e) Phosphorus distribution coefficient (g extractable P/kg Soil)/(g dissolved P/m^3 soil solution); and
    f) Organic matter content (in each texture class).
2) Watershed/Field Properties:
    a) Slope;
    b) Slope length;
    c) Surface area;
    d) Total flow (runoff and drainage); and
    e) Rainfall erosivity (R factor in USLE);
3) Agricultural Practices:
    a) Cropping factor (C in USLE)
    b) Practice factor (P in USLE)
    c) Nitorgen and Phosphorus fertilization rates;
    d) Tillage depth; and
    e) Crop residue management.

The methodology is based upon the Universal Soil Loss Equation (USLE), which has been developed by the USDA for use in the soil conservation area. This equation and its tabulated parameter estimates are based upon a large data-collection and analytical effort. A number of additions have been made in this study in order to make the USLE a more useful tool for evaluating water quality impacts. The formulations and calibrations of the additional functions are based upon substantially less data and analysis than the USLE and could therefore be described as less objective. Analysis of further experimental and monitoring data could lead to a more objective basis for some of the assumed functional forms and parameter estimates. However, for this study relatively subjective assessments are relied upon -- substantiated when possible with data and the opinions of experts. A sensitivity analysis will help to determine which assumptions are most important in evaluating both the absolute and the relative impacts of agricultural practices on watershed emissions and on downstream water quality.

The methodology is applicable to a single field or plot of uniform characteristics. In this preliminary assessment of agricultural practices, a hypothetical watershed is assumed to be comprised of a number of fields of equal characteristics. This provides a rough measure of the unit emissions and water quality impacts of a given field/soil type/agricultural practice combination. The methodology could be applied to a heterogeneous watershed consisting of a number of areas, each with its own set of field/soil type/practice specifications. The effects of heterogenous watershed characteristics on practice evaluations and conclusions are considered higher level questions, which are best addressed subsequent to an analysis of homogenous watersheds.

In order to be compatible with the economic analysis carried out in this study the models are calibrated to three different field/soil types which are characteristic of the Black Creek Watershed, Indiana. A research and demonstration program sponsored by the EPA (Christenson and

Wilson, 1976, Lake and Morrison, 1975, has provided some data for calibrating the models to these three field and soil types. In the discussion below, general (i.e., process-related) parameter estimates are presented immediately after the corresponding functions. Soil- and practice-specific parameters are presented and discussed in a separate section. In view of the preliminary nature of many of the functional forms and parameter estimates, a final sensitivity analysis is essential to understanding and assessing the feasibility of applying the methodology in a planning context.

Sediment

Estimation of gross sheet and rill erosion rates are obtained through use of the Universal Soil Loss Equation (Wischmeier and Smith, 1972):

$$S = .224\ RKL_S\ PC \qquad (1)$$

where,

S = gross erosion rate (kg/m^2-yr)

R = rainfall erosivity factor

K = soil erodibility factor (tons/acre-year)

L_S = length/slope factor

P = practice factor

.224 = dimensional factor ((kg/m^2)/(tons/acre))

The C factor is computed considering the seasonal variations in soil cover and rainfall erosivity, as prescribed by Wischmeier and Smith. Detailed discussions of the bases, assumptions and parameter estimates of this model are available elsewhere (Wischmeier and Smith, 1972, Wischmeier, 1976, EPA and USDA, 1975, and MRI, 1976).

The length/slope factor is computed using the following function (Wischmeier and Smith, 1972):

$$L_s = \sqrt{L}\,(.0076 + .0053g + .0076g^2) \qquad (2)$$

where,

L = length of slope (feet)

g = slope gradient (percent)

Eroded sediment is usually enriched in fine particles, relative to the surface soil of its origin. This enrichment is apparent in edge-of-field sediment measurements (Soltenberg and White, 1953; Kilner, 1960), in river sediments measurements (Rausch and Heinemann, 1975; Jones et al, 1977) and in lake bottom sediment measurements (Stall, 1972). Since finer fractions of soil have higher surface areas per unit mass, they generally have higher adsorption capacities and higher nutrient and organic matter contents, expressed as grams per gram of solid (Buckman and Brady, 1960).

Enrichment of fine particles in sediment is considered here in order to permit explicit calculation of the nutrient and organic matter contents of eroded sediment based upon the measured nutrient and organic matter contents of various soil size fractions. This is an alternative to the use of gross "enrichment ratios" (MRI, 1976). By explicitly considering the clay, silt, and sand fractions in soil and eroded sediment, differences in the behavior of these fractions in rivers and in impoundments can be modeled. This also forms a basis for future development of models for other constitutents, such as biocides or biocide residues, which may also show preferential adsorption to fine particles.

The enrichment phenomenon has been shown to increase with decreasing gross erosion and runoff rates. For instance, Stoltenberg and White (1953) found that the clay content of eroded material from a soil containing 16 percent clay increased from 25 percent to 60 percent as runoff rates decreased from 2.84 to .01 inches/hour. Raush and Heinemann (1976) found that the clay fraction in river sediment from a watershed in Missouri increased from 30 percent to 80 percent as peak storm flows decreased from 10 to $.3\text{m}^3/\text{sec}$. An empirical function for computing phosphorus enrichment ratios developed by Massey et al (1953) and presented by MRI (1976) is qualitatively consistent with this behavior, in that it predicts an increase in the phosphorus enrichment ratio, given a decrease in either the total sediment concentration or the total erosion rate.

In order to account for enrichment, the texture of eroded sediment is computed as a function of soil texture and S, the gross erosion rate, using the following assumed relationships:

$$X_{CL}^{E} = X_{CL}^{S} + (X_{CL}^{M} - X_{CL}^{S}) \left(\frac{K_1}{K_1 + S}\right) \qquad (3)$$

$$X_{SA}^{E} = X_{SA}^{S} \left(\frac{S}{S + K_2}\right) \qquad (4)$$

$$X_{SI}^{E} = 1 - X_{CL}^{E} - X_{SA}^{E} \qquad (5)$$

$$X_{CL}^{M} = 1 - \frac{X_{SI}^{S}}{K_3} \qquad (6)$$

where,

$X_{CL}^{E}, X_{SI}^{E}, X_{SA}^{E}$ = clay, silt, and sand fractions of eroded sediment

$X_{CL}^{S}, X_{SI}^{S}, X_{SA}^{S}$ = clay, silt and sand fractions of surface soil

K_1, K_2, K_3 = empirical parameters

X_{CL}^{M} = maximum clay content of eroded sediment

According to these equations, sediment texture approaches that of surface soil as S approaches infinity, while the clay, silt, and sand fractions approach X_{CL}^{M}, $1 - X_{CL}^{M}$, and 0 as S approaches zero. The following tentative parameter values are assumed:

$K_1 = .50 \text{ kg/m}^2 - \text{year}$

$K_2 = 20.0 \text{ kg/m}^2 - \text{year}$

$K_3 = 2.0$

The behavior of sediment texture as a function of S for these parameter values and for a typical soil texture is depicted in Figure B-2. While explicit, quantitative justification for the assumed parameter values cannot be given, sediment texture computed according to this scheme agrees qualitatively with the data discussed above. Direct calibration and testing should be done, when the appropriate data are available.

Estimates of gross erosion for each texture class are converted to watershed emission rates by application of a sediment delivery ratio, which is computed as a function of downstream watershed area and texture class:

$$S^D_{CL} = SX^E_{CL}\ Dd_{CL} \tag{7}$$

$$S^D_{SI} = SX^E_{SI}\ Dd_{SI} \tag{8}$$

$$S^D_{SA} = SX^E_{SA}\ Dd_{SA} \tag{9}$$

where,

S^D_{CL}, S^D_{SI}, S^D_{SA} = delivered clay, silt and sand (kg/m^2 - year)

D = reference delivery ratio

d_{CL}, d_{SI}, d_{SA} = delivery ratio multiplier for clay, silt and sand fractions.

Total watershed area has been often used as an independent variable for predicting mean sediment delivery ratios (EPA/USDA, 1976; Vanoni, 1975).

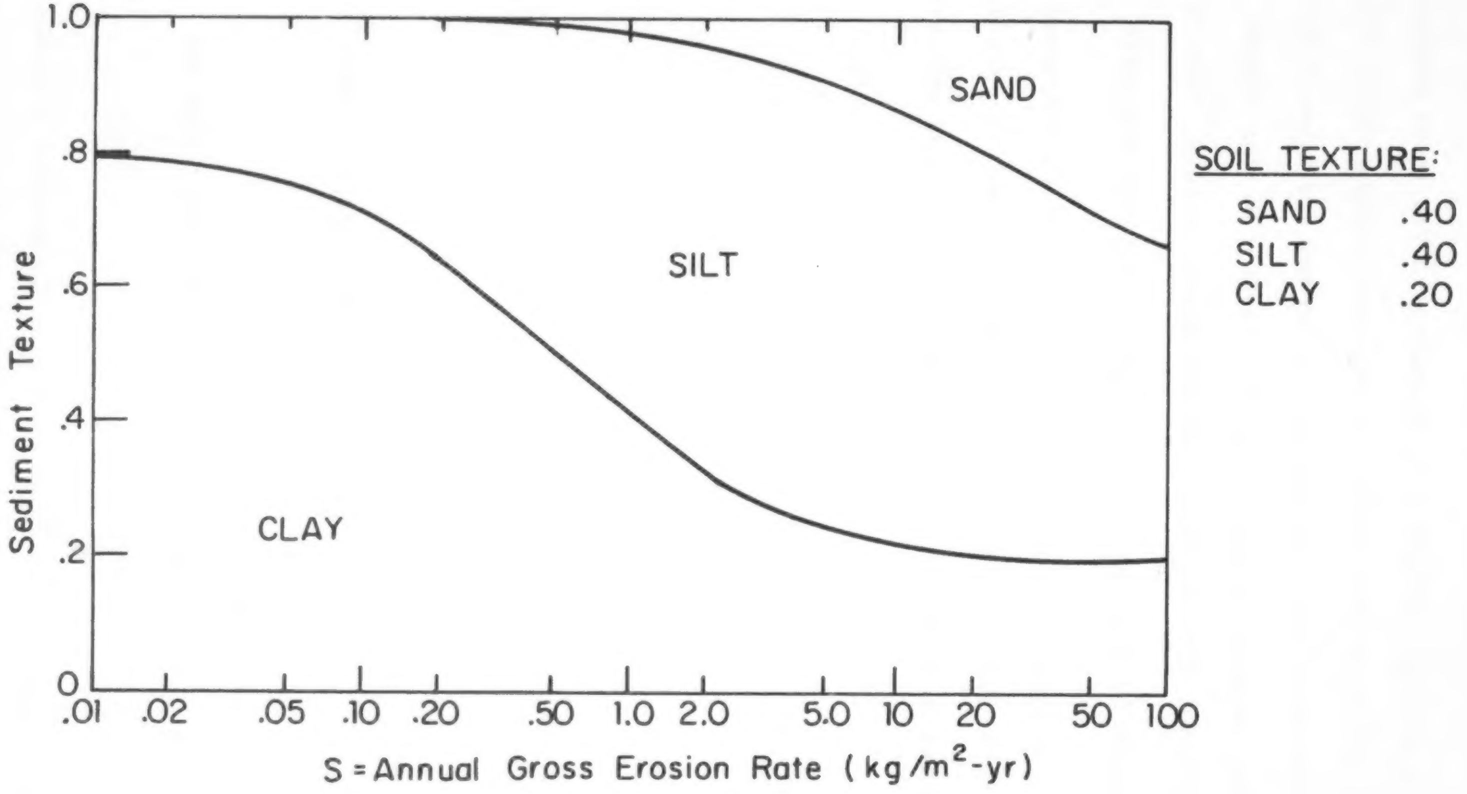

Figure B-2. Relationship between Gross Erosion Rate and Sediment Texture for a Typical Loam Soil

Data from a table in EPA/USDA (1976), have been fit to the following empirical function:

$$\bar{D} = K_4 A_W^{-K_5} \qquad (10)$$

where

K_4 = .34

K_5 = .20

A_W = total watershed area (km^2)

$\bar{D}$ = mean delivery ratio

While other factors have been employed as delivery ratio predictors, the above functional form has been most widely used (Vanoni, 1975). In a heterogeneous watershed, however, direct application of equation (10) to the area[1] mean gross erosion rate could lead to errors, because it does not take into account the fact that delivery ratios are likely to be higher in the lower contours of a watershed than in the upper contours, due to shorter transport distances. This can be demonstrated quantitatively. By differentiating the product of the total watershed area and the average delivery ratio (computed according to equation (10)), it can be shown that equation (10) implies the following:

$$D_{A_D} = (1 - K_5)\, K_4 A_D^{-K_5} = .27\, A_D^{-.20} \qquad (11)$$

where,

D_{A_D} = localized delivery ratio for a region at the uppermost contour of a watershed

A_D = watershed area downstream (km^2)

D_{A_D} is a localized delivery ratio, whereas $\bar{D}$, in equation (10), represents the average value over an entire watershed. Equation (11) predicts lower effective delivery ratios in higher areas within a given watershed. For application in heterogeneous watersheds, the D value in equations (7) to (9) should be computed for each sub-area using equation (11) and the downstream watershed area, as opposed to the total watershed area. In homogeneous watersheds, results are independent of whether equation (10) or equation (11) is used.

A graph in MRI (1976) indicates that delivery ratios for clay, silt, and sand are approximately in the ratios 5:3:1. If these ratios are normalized to a d_{si} value of 1, the following delivery ratio multipliers are calculated:

$d_{CL} = 1.67$

$d_{SI} = 1.00$

$d_{SA} = 0.33$

These multipliers are assumed to be independent of location in a given watershed.

The total sediment load transported to a downstream impoundment is computed as the sum over the texture classes multiplied by the ratio of watershed area to impoundment surface area:

$$S^D = (S^D_{CL} + S^D_{SI} + S^D_{SA}) \frac{A_W}{A_I} \qquad (12)$$

where

S^D = impoundment sediment load (kg/m^2 surface area-year)

A_I = impoundment surface area (km^2)

The computed sediment delivery of each texture class is used to estimate sedimentation rate, phosphorus trapping rate, and suspended solids concentration in the impoundment, according to the methodology discussed separately (see Appendix C).

Runoff and Percolation

Predictions of the emissions of soluble phosphorus and color are dependent upon estimates of average surface runoff rates. The total flow rate from a watershed or field is assumed to consist of two components, the sum of which is independent of the agricultural practice:

$$q = q_R + q_D \qquad (13)$$

where

q = total flow rate (m/year)

q_R = surface runoff rate (m/year)

q_D = subsurface drainage (m/year).

This essentially assumes that average evapotransporation rates are not significantly influenced by the mode of farm operation. The runoff component, q_R, is evaluated as:

$$q_R = q_R^o(1-f_R) \tag{14}$$

where

q_R^o = baseline runoff rate for straight-row, continuous corn on soil of the appropriate hydrologic group (m/year)

f_R = runoff reduction factor appropriate for agricultural practice and soil type.

This method is based upon the results of simulations performed by Woolhiser (1975, 1977), using a modification of the SCS Curve Number runoff model (SCS, 1971). These simulations have provided regional estimates of average annual runoff rates for soils in various Hydrologic Groups (SCS, 1971) and for two basic agricultural practices: straight row, continuous corn and continuous meadow, which represent the approximate upper and lower limits of q_R, respectively, as influenced by agricultural practice. The former are used here as reference values and equated to q_R^o for the appropriate soil group and region. Some of Woolhiser's simulation results are summarized in Table B-1. Regional variations in q_R^o are shown in Figures B-3 through B-6 for soils in various Hydrologic Groups.

Values of f_R are sensitive both to soil type and to agricultural practice, since some practices are only effective on certain soil types. Estimation of f_R values is based upon Woolhiser's Table 14 and Figure 32

Table B-1. Results of Direct Runoff Simulations (EPA/USDA, 1975)

Location	Hydrologic[1] soil group	Estimated mean annual direct runoff (inches)	% reduction in annual runoff			Estimated mean growing season direct runoff (inches)	% reduction in growing season runoff		
			Contouring, R 9	Contoured and terraced, R 9, R 12	Meadow R 16		Contouring, R 9	Contoured and terraced, R 9, R 12	Meadow R 16
Wichita, KS	B	2.2	11	22	81	1.7	15	29	80
Columbia, MO	D	5.3	20	37	75	2.9	31	53	68
Columbus, OH	C	3.6	12	21	75	1.0	10	24	73
Des Moines, IA	B	1.6	18	27	89	0.9	24	38	85
Grand Isl., NB	B	1.5	16	23	88	0.9	12	26	90
Sioux Fall, SD	B	1.2	8	16	94	0.7	13	28	95
Cairo, IL	B	4.7	1	9	78	1.3	11	24	80
Indianapolis, IN	C	5.2	11	21	75	1.7	23	42	74
Springfield, IL	B	2.6	12	22	89	1.4	12	24	83
Houston, TX	D	11.3	17	36	52	5.9	17	36	49
Raleigh, NC	B	2.4	16	32	88	1.1	19	39	88
Charleston, WV	C	4.0	14	25	75	1.2	25	36	62
Birmingham, AL	B	7.2	11	21	72	1.8	14	29	74
Columbia, SC	B	4.4	17	31	83	2.3	21	39	82
Dallas, TX	D	8.3	15	32	55	5.1	14	29	53
Little Rock, AR	D	13.4	12	24	58	5.5	11	24	57
Buffalo, NY	B	1.5	13	23	89	0.7	33	54	100
Boston, MA	A	2.2	6	15	94	0.6	11	26	85
Scranton, PA	C	2.6	16	30	82	0.8	21	32	78
Pittsburgh, PA	C	3.2	10	19	83	0.9	22	41	85
Seattle, WA	B	2.9	20	35	85	0.1	33	55	89

---

[1] More than 4,000 soils in the United States and Puerto Rico have been assigned by the Soil Conservation Service to Hydrologic soil groups A through D on the basis of their runoff potential. Hydrologic group A has low runoff potential; group D has a high runoff potential; and B and C are intermediate. For a more detailed discussion, see Volume II, Appendix A.

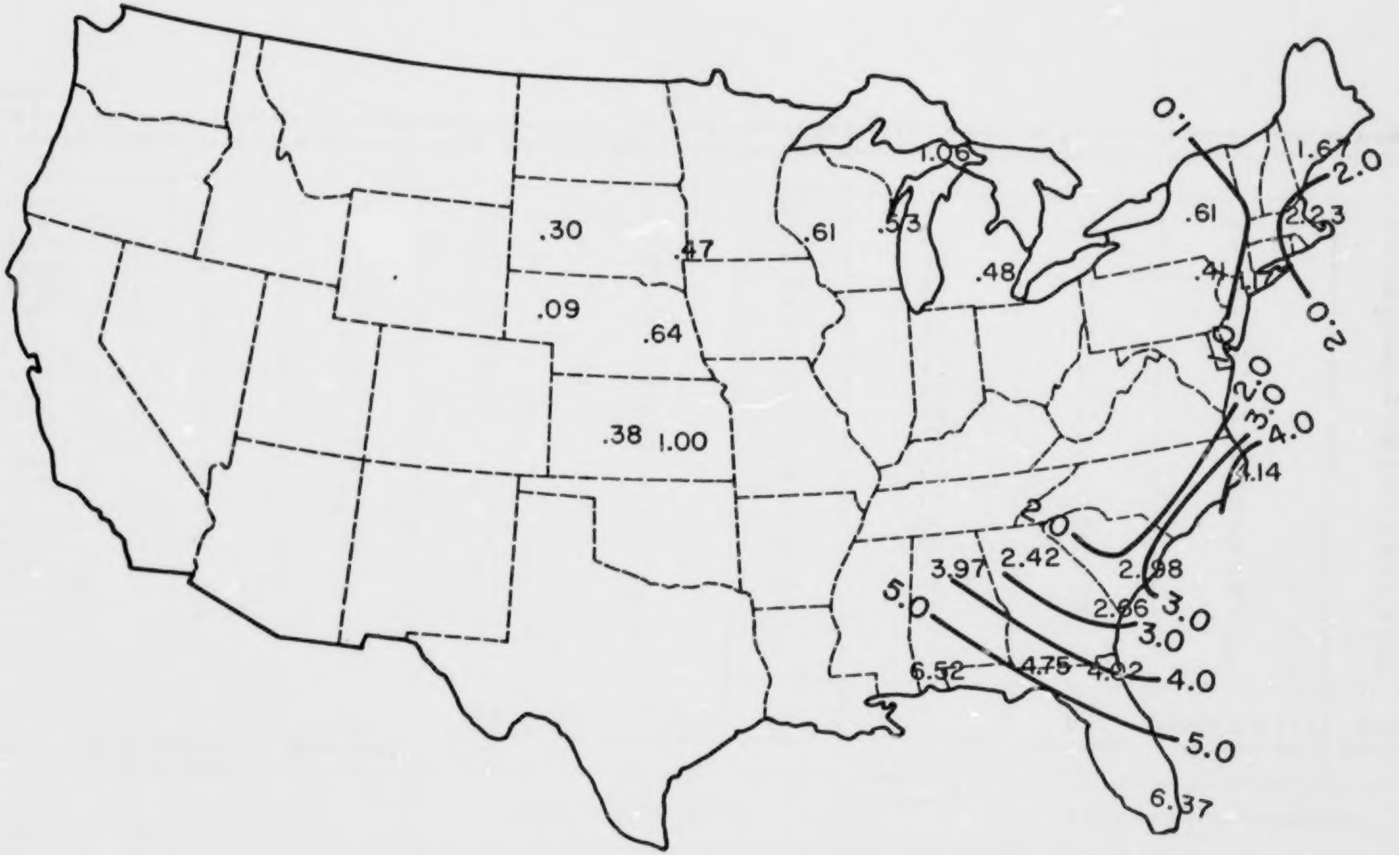
1.0
1.67
2.0
.61
2.23
.41
2.0
1.06
.53
.61
.48
.30
.47
.09
.64
.38
1.00
2.0
3.0
4.0
4.14
2.0
3.97
2.42
2.98
2.86
3.0
3.0
5.0
6.52
4.75
4.02
4.0
5.0
6.37

Figure B-3. Mean Annual Potential Direct Runoff in Inches. Straigt-row Corn in Good Hydrologic Condition -- Hydrologic Soil Group A. (Woolhiser, 1976)

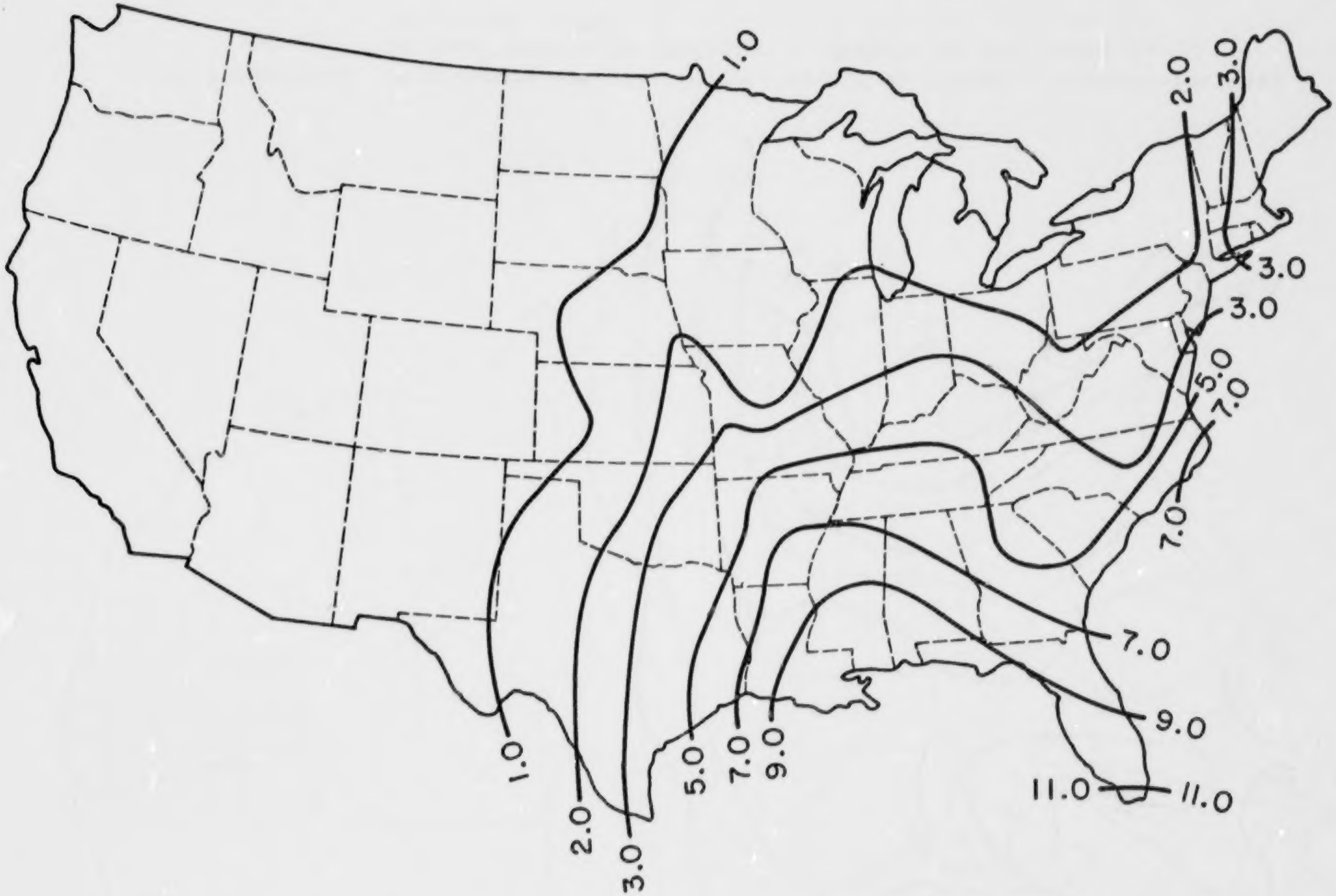
1.0
2.0
3.0
3.0
3.0
5.0
7.0
7.0
7.0
9.0
11.0
11.0
1.0
2.0
3.0
5.0
7.0
9.0

Figure B-4. Mean Annual Potential Direct Runoff in Inches. Straight-row Corn in Good Hydrologic Condition -- Hydrologic Soil Group B. (Woolhiser, 1976)

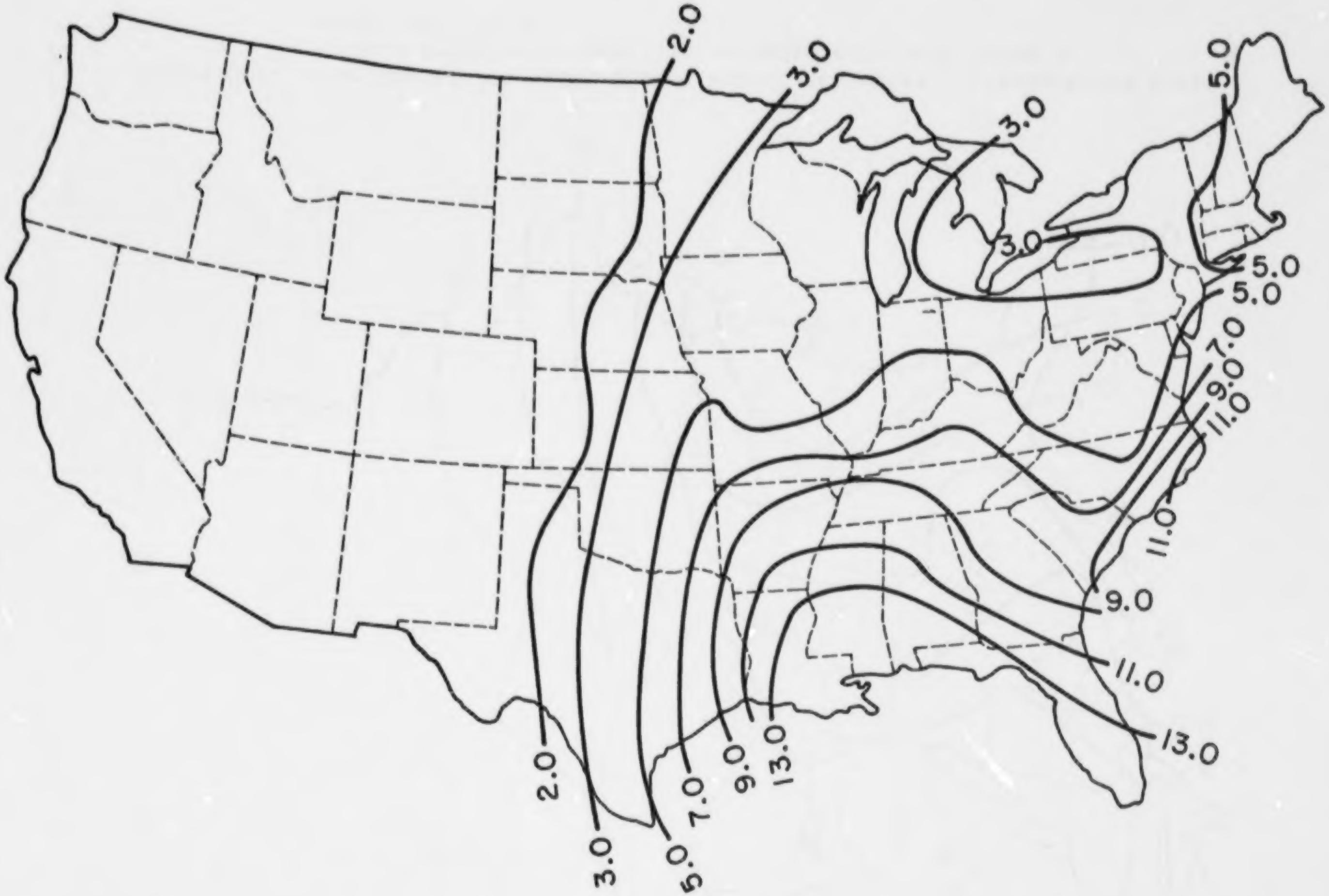
2.0
3.0
3.0
3.0
5.0
5.0
5.0
7.0
9.0
11.0
11.0
9.0
11.0
13.0
2.0
3.0
5.0
7.0
9.0
13.0

Figure B-5. Mean Annual Potential Direct Runoff in Inches. Straight-row Corn in Good Hydrologic Condition -- Hydrologic Soil Group C. (Woolhiser (1976)

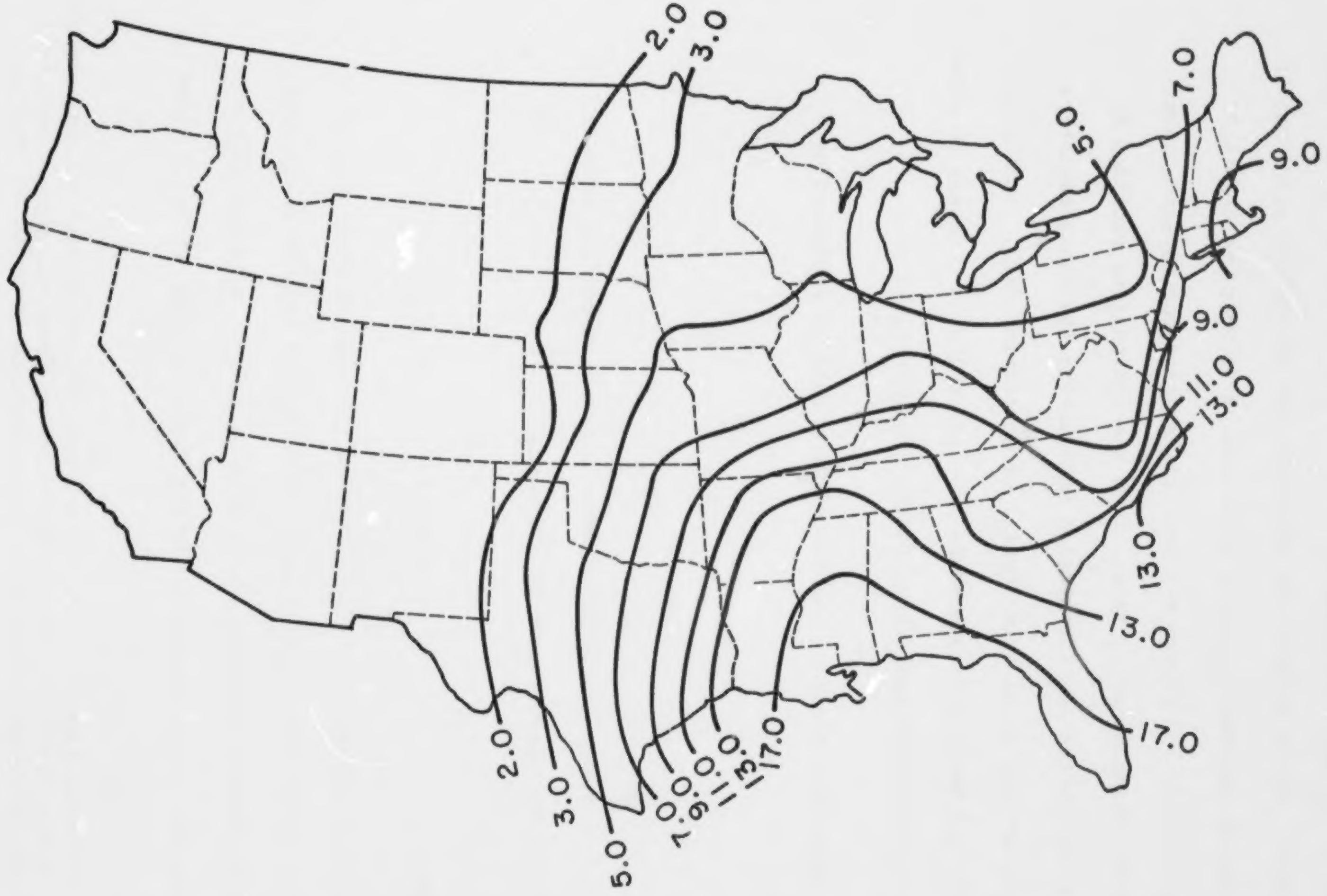
2.0
3.0
5.0
7.0
9.0
9.0
9.0
11.0
13.0
13.0
13.0
17.0
2.0
3.0
5.0
7.0
9.0
11.0
13.0
17.0

Figure B-6. Mean Annual Potential Direct Runoff in Inches. Straight-row Corn in Good Hydrologic Condition -- Hydrologic Soil Group D. Woolhiser (1976)

(EPA/USDA, 1975), which are reproduced here as Table B-2 and Figure B-7, respectively. In the former, the effectiveness of various practices in reducing runoff are qualitatively evaluated as "slight," "moderate," and/or "substantial." Figure B-7 provides a basis for obtaining semi-quantitative estimates of f_R values from the indications provided by Table B-2.* The latter are interpreted considering the characteristics of the soil and any local experimental or monitoring data. Woolhiser's simulations and hence this procedure are less reliable in areas in which snowmelt is a dominant hydrologic factor (Woolhiser, 1975).

The subsurface drainage, or percolation rate is estimated by difference:

$$q_D = q - q_R \tag{15}$$

Estimates of q values are obtained from regional streamflow records. A typical value for the Cornbelt is .25 m/year.

Phosphorus

Phosphorus emissions are estimated as the sums of three separate components: extractable particulate, soluble, and soluble phosphorus leached from surface crop residues during snowmelt. Only the NH_4F/HCl extractable portion of the particulate phosphorus (Bray P) is included.

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* The reduction factors in Figure B-7 are related to mean growing season potential direct runoff, which can be estimated from mean annual potential direct runoff by comparing the appropriate columns in Table B-1. The percentage reductions are assumed to be appropriate for both time scales. (See Table B-1.)

Table B-2. EFFECTS OF VARIOUS PRACTICES ON DIRECT RUNOFF (EPA/USDA, 1975)

No.	Runoff Control Practice	Practice Highlights
R 1	No-till plant in prior crop residues	Variable effect on direct runoff from substantial reductions to increases on soils subject to compaction.
R 2	Conservation tillage	Slight to substantial runoff reduction.
R 3	Sod-based rotations	Substantial runoff reduction in sod year; slight to moderate reduction in rowcrop year.
R 4	Meadowless rotations	None to slight runoff reduction.
R 5	Winter cover crop	Slight runoff increase to moderate reduction.
R 6	Improved soil fertility	Slight to substantial runoff reduction depending on existing fertility level.
R 7	Timing of field operations	Slight runoff reduction.
R 8	Plow plant systems	Moderate runoff reduction.
R 9	Contouring	Slight to moderate runoff reduction.
R 10	Graded rows	Slight to moderate runoff reduction.
R 11	Contour strip cropping	Moderate to substantial runoff reduction.
R 12	Terraces	Slight increase to substantial runoff reduction.
R 13	Grassed outlets	Slight runoff reduction.
R 14	Ridge planting	Slight to substantial runoff reduction.
R 15	Contour listing	Moderate to substantial runoff reduction.
R 16	Change in land use	Moderate to substantial runoff reduction.
R 17	Other practices Contour furrows Diversions Drainage Landforming	 Moderate to substantial reduction. No runoff reduction. Increase to substantial decrease in surface runoff. Increase to slight runoff reduction.
R 18	Construction of ponds	None to substantial runoff reduction. Relatively expensive. Good pond sites must be available. May be considered as a treatment device.

This is considered by some to be a measure of the "available" particulate phosphorus (Römkens and Nelson, 1974). The remaining inorganic and organic particulate forms are assumed to be unavailable to support algal growth in downstream impoundments. Extractable and total particulate phosphorus data from soils in the Black Creek area (Sommers et al, 1975) generally support Taylor's (1967) suggestion that about ten percent of the phosphorus in soils is available for aquatic plant growth. Other investigators have used other definitions of "available P" which would correspond to lower percentages of total P (Porter, 1975). This is an important assumption which is critical to evaluating the effects of erosion controls on eutrophication and requires additional study.

The first step in estimating phoshorus emissions is to evaluate the extractable phosphorus content of the surface soil as a function of

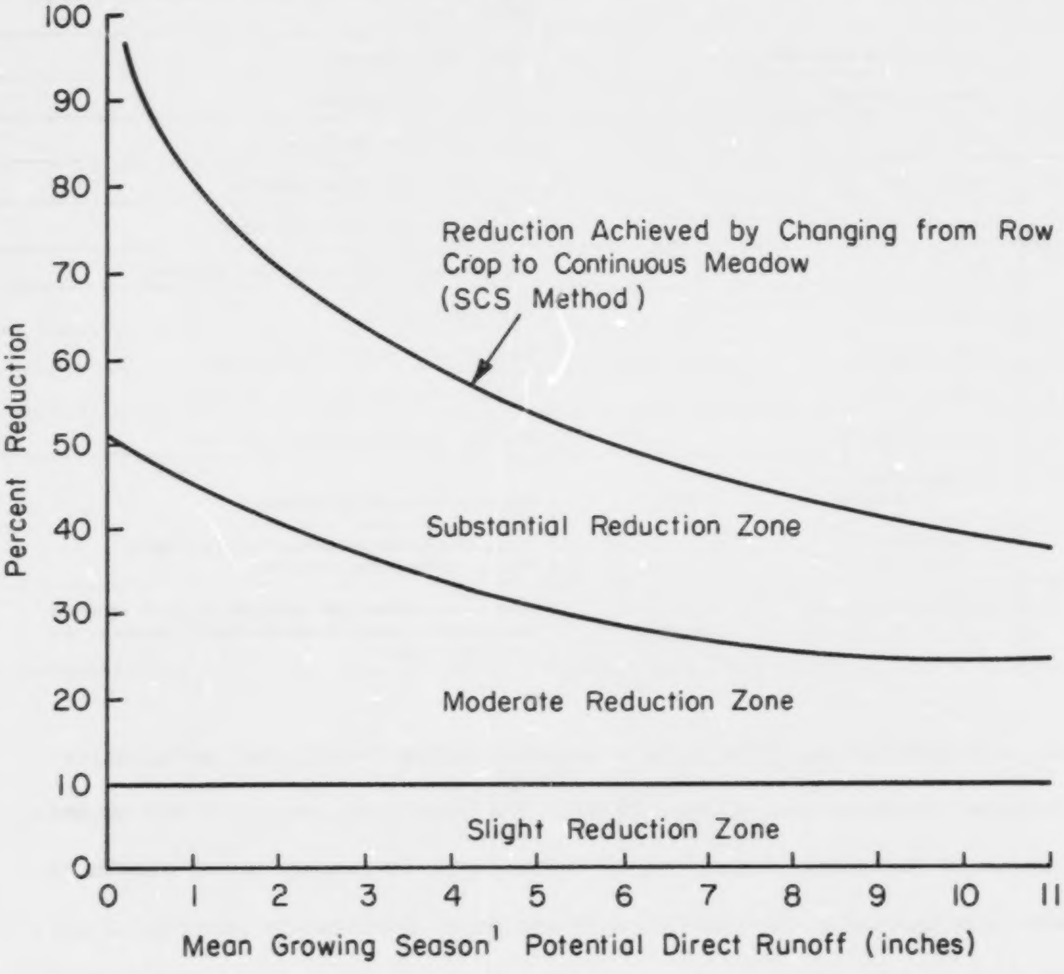

Figure B-7. Definition of Ranges of Reduction in Mean Growing Season Direct Runoff (EPA/USDA, 1975) fertilization rate, tillage depth, and baseline soil phosphorus levels. Direct measurements of the extractable phosphorus contents of the various soil size fractions are relied upon for model calibration. The baseline, average soil phosphorus level is computed from:

$$P^{o} = P^{o}_{CL} X^{S}_{CL} + P^{o}_{SI} X^{S}_{SI} + P^{o}_{SA} X^{S}_{SA} \qquad (16)$$

where

P^{o} = baseline, average phosphorus content of surface soil (gP/kg soil),

P^{o}_{CL}, P^{o}_{SI}, P^{o}_{SA} = baseline extractable phosphorus content of clay, silt, and sand fractions in surface soil (gP/kg solid).

The rates and depths of phosphorus addition to surface soils have been observed to influence the surface soil phosphorus content (Timmons, et al, 1973; Brigham, 1977; Römkens and Nelson, 1974; Römkens, et al, 1973). A nearly linear relationship between the rate of fertilizer addition and the concentration of available phosphorus in surface soil has been reported by Romkens and Nelson (1974). Timmons, et al. (1973) detected increases of about .005 and .035 g available P/kg in eroded sediment from plots receiving equal fertilizer doses which were plowed under and surface broadcast, respectively. These increases are relative to unfertilized plots, the sediment from which averaged about .010 gP/kg. By decreasing the depths of fertilizer incorporation, use of minimum tillage methods causes an increase in the surface soil phosphorus level, which tends to offset the benefits of such practices as means of controlling phosphorus losses through erosion (Brigham, 1977).

The increase in surface soil phosphorus over baseline levels due to fertilization and tillage method is estimated as follows:

$$\Delta P = \frac{F_P}{\rho_S Z_T K_6} \tag{17}$$

where

ΔP = increase in surface soil phosphorus (gP/kg soil)

F_P = fertilization rate ($gP/m^2 - yr$)

ρ_S = surface soil density (kg/m^3)

Z_T = effective tillage depth (m)

K_6 = empirical parameter $(yr)^{-1}$

The empirical parameter K_6 accounts for removal and conversion of fertilizer phosphorus into unavailable forms. The inverse of K_6 is a measure of the fraction of the added fertilizer phosphorus which is recoverable as available soil phosphorus. Laboratory studies by Römkens and Nelson (1974) have given fractions ranging from .25 to .76 for various soil types. A value of .50 is assumed here, corresponding to a K_6 value of 2 $year^{-1}$. Combined with a ρ_S estimate of 1300 kg/m^3 (Buckman and Brady, 1960), this gives increases of .037 and .005 gP/kg for minimum tillage (Z_T = 1 inch = .025m) and conventional tillage (Z_T = 7 inches = .18m), respectively, when a typical fertilization rate of 2 gP/m^2-yr is used. These results are in line with those of Timmons et al. (1973), as discussed above.

With the increase in surface soil phosphorus level computed according to the above scheme, corresponding increases in the phosphorus content of each texture class are evaluated as follows:

$$P^S = P^o + \Delta P \tag{18}$$

$$P^S_{CL} = P^o_{CL} \quad (1 + \frac{\Delta P}{P^o}) \tag{19}$$

$$P^S_{SI} = P^o_{SI} \quad (1 + \frac{\Delta P}{P^o}) \tag{20}$$

$$P^S_{SA} = P^o_{SA} \quad (1 + \frac{\Delta P}{P^o}) \tag{21}$$

where

P^S = surface soil phosphorus content (gP/kg soil)

$P^S_{CL}, P^S_{SI}, P^S_{SA}$ = phosphorus content of clay, silt, and sand fractions (gP/kg soil).

The load of sediment phosphorus transported downsteam to the impoundment is evaluated as the sum over the texture classes:

$$LP_{SED} = (S^D_{CL}\ P^S_{CL} + S^D_{SI}\ P^S_{SI} + S^D_{SA}\ P^S_{SA})\ \frac{A_w}{A_I} \tag{22}$$

where,

LP_{SED} = loading of available phosphorus in sediment (gP/m^2 impoundment surface area-yr)

The second component of phosphorus loading is the soluble fraction, which is exported from the watershed in surface runoff and subsurface drainage:

$$LP_{SOL} = (q_R\ C_R + q_D\ C_D)\ \frac{A_w}{A_I} \tag{23}$$

where

C_R = soluble phosphorus concentration in surface runoff (g/m^3)

C_D = soluble phosphorus concentration in drainage (g/m^3)

LP_{SOL} = loading of soluble phosphorus transported to the impoundment (g/m^2-yr).

The runoff and drainage rates, q_R and q_D, respectively, are estimated according to the methods described previously. Soluble phosphorus concentrations in surface runoff are computed from the average eroded sediment contents, assuming a linear adsorption isotherm:

$$C_R = \frac{P^E}{\gamma_P} \tag{24}$$

$$P^E = X^E_{CL}\ P^S_{CL} + X^E_{SI}\ P^S_{SI} + X^E_{SA}\ P^S_{SA} \tag{25}$$

where

γ_P = phosphorus distribution coefficient (m^3/kg)

P^E = average available phosphorus content of eroded sediment (g/kg).

γ_P is a soil-specific parameter which is evaluated based upon soil available phosphorus and soluble equilibrium phosphorus concentrations (Taylor and Kunishi, 1971). Based upon data from Römkens and Nelson (1974), γ_P ranges from .1 to 1 m^3/kg for different soil types. Data from the Black Creek area (Sommers et al, 1975) indicate a range of .5 to 1 m^3/kg.

Drainage is assumed to be in equilibrium with relatively phosphorus-deficient subsoils. Accordingly, C_D is set at a relatively low value of .03g/m^3. This is typical of soluble phosphorus concentrations in drainage from mostly forested watersheds in the Cornbelt, from which surface runoff is generally insignificant (Omernik, 1976).

The final phosphorus export component is that which leaches from surface crop residues during snowmelt periods. This component is soluble and is considered separately because the phosphorus concentrations in snowmelt runoff may not equilibrate with frozen surface soils. The freezing, thawing, and leaching cycle which culminates during initial snowmelt may release substantial quantities of dissolved phosphorus from residues left on the soil surface after fall harvest. In studies of runoff from natural rainfall erosion plots, Timmons et al (1968) found that more water-soluble phosphorus was lost in snowmelt runoff from seedling alfalfa than from other periods or cropping sequences studied (continuous corn, rotation corn, and rotation oats). Laboratory studies (Timmons et al, 1970) revealed that one freezing/thawing/leaching cycle could release 9, 28, 6 and 5% of the total phosphorus in residues from alfalfa, bluegrass, barley and oats, respectively. Three consecutive cycles released 36, 64, 13 and 16% of the phosphorus in these residues, respectively. Timmons, et al (1970) estimated potential emissions under field conditions based upon the laboratory data obtained for one cycle and showed that these amounts could be appreciable relative to other soluble phosphorus losses. A major uncertainly in their estimates is the extent to which snowmelt phosphorus concentrations may equilibrate with (i.e., be adsorbed by) partially thawed surface soils or stream bank sediments.*

Despite the relative lack of data in this area, inclusion of this component is considered important for evaluating the impacts of tillage methods on water quality with regard to eutrophication. No-till methods tend to leave crop residues on the surface and thus create a greater potential for leaching losses in snowmelt than conventional tillage methods, which incorporate residues into the soil.

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* Data from the Black Creek Watershed (Nelson, 1977) also indicate high soluble inorganic phosphorus (SIP) concentrations in snowmelt. At one sampling station, for instance, the average SIP concentrations in 1976 snowmelt was .19 g/m^3, compared with an annual average concentration of .05 g/m^3.

The following function is employed to estimate this component:

$$LP_{RES} = RES_P \ (1 - F_{RES}) \ K_7 \ \frac{A_w}{A_I} \qquad (26)$$

Where

LP_{RES} = impoundment phosphorus loading attributed to leaching from crop residues during snowmelt (gP/m^2-yr)

RES_P = average mass of residue phosphorus on the soil surface after harvest (gP/m^2)

F_{RES} = fraction of residues plowed under for a given tillage method

K_7 = fraction of surface residue P leached in snowmelt $(year)^{-1}$.

A nominal value of 0.01 has been tentatively assumed for K_7. This value is low, relative to the range assumed by Timmons, et al (1970), .05 to .28. A lower value is probably more appropriate, considering the possibility of partial adsorption by surface soils and river bank sediments. The nominal value has been assumed merely to demonstrate the potential importance of this component of the available phosphorus losses from agricultural operations. This, in turn, indicates a need for additional data in order to permit a more quantitative definition of this component.

The total phosphorus loading is evaluated as the sum of the sediment, soluble, and snowmelt residue components:

$$LP_T = LP_{SED} + LP_{SOL} + LP_{RES} \tag{27}$$

where

LP_T = available phosphorus load transported to the downstream impoundment (g/m^2-year).

This value is used to evaluate the water quality response in the impoundment with regard to transparency and chlorophyll-a.

Soluble Nitrogen

Because nitrogen is generally more mobile in soil systems than phosphorus, estimates of average soluble nitrogen export from agricultural areas are based upon mass balances, rather than upon computed soil erosion rates and adsorption chemistry. Other investigators (Onishi, et al, 1974; Tanji, et al, 1977; Harmeson, et al, 1971) have employed similar models for the purpose of obtaining rough estimates of potential nitrogen emissions. A nitrogen mass balance is assumed here to consist of four input and three output components:

$$\dot{N}_{FX} + \dot{N}_{FE} + \dot{N}_R + \dot{N}_M = \dot{N}_Y + \dot{N}_D + \dot{N}_L \tag{28}$$

where

$\dot{N}_{FX}$ = fixation rate (gN/m^2-year)

$\dot{N}_{FE}$ = fertilization rate (gN/m^2-year)

$\dot{N}_R$ = rainfall nitrogen input rate (gN/m^2-year)

$\dot{N}_M$ = soil mineralization rate (gN/m^2-year)

$\dot{N}_Y$ = crop yield (gN/m^2-year)

$\dot{N}_D$ = denitrification rate (gN/m^2-year)

$\dot{N}_L$ = total runoff and drainage losses (gN/m^2-year)

The fixation component, $\dot{N}_{FX}$, accounts for nitrogen fixation by leguminous crops and is estimated from the yield and nitrogen content of such crops accounting for extra nitrogen fixed and contributed to the soil in the forms of residues and root exudates. The fertilization component, $\dot{N}_{FE}$ is based upon the assumed fertilization rate. The regional rainfall component for northern Indiana is estimated at .3 gN/m^2-year (MRI, 1976). Mineralization accounts for the breakdown of soil organic nitrogen compounds and the resultant net release of inorganic nitrogen forms. This is perhaps the most difficult of the input terms in the equation to evaluate. Onishi, et al (1974), have equated this component to the nitrogen content of the crop yield obtained when no fertilizer is applied. A generalized nitrogen response curve for corn presented by Lucas, et al (1977), indicates that yields without fertilization are about 45 percent of the yields obtained under optimal fertilization. The $\dot{N}_M$ term is assumed to equal the nitrogen equivalent of this corn yield, less the precipitation input.

On the other side of equation (28), the yield component, $\dot{N}_Y$, is estimated from crop yield and assumed nitrogen content. It includes only the harvested product (not the residues, which are assumed to be returned to the soil). The denitrification component, $\dot{N}_D$, is estimated as a fraction of the calculated net nitrogen input rate:

$$\dot{N}_D = (\dot{N}_{FX} + \dot{N}_{FE} + \dot{N}_R + \dot{N}_M - \dot{N}_Y)F_D \qquad (29)$$

where

F_D = fraction of excess nitrogen which is denitrified

F_D is specified for each soil type; poorly drained soils have higher values due to lower oxygen levels and lower leaching rates. The final component, $\dot{N}_L$, accounts for soluble nitrogen losses and is evaluated by difference:

$$\dot{N}_L = \dot{N}_{FX} + \dot{N}_{FE} + \dot{N}_R + \dot{N}_M - \dot{N}_Y - \dot{N}_D \qquad (30)$$

No distinctions are made between nitrogen losses in surface runoff and subsurface drainage. Because of difficulties involved in estimating the denitrified fraction, estimates of nitrogen losses obtained in this way are probably better for relative comparisons of practices (e.g., percentage differences) than as absolute levels.

Nitrogen is assumed to be transported conservatively to the downstream impoundment at the following rate:

$$L_N = \dot{N}_L \frac{A_W}{A_I}$$

where

L_N = impoundment nitrogen loading (gN/m^2-year)

This scheme ignores particulate nitrogen losses attributed to soil erosion. Sommers, et al (1975), measured total and exchangeable nitrogen in sediment from rainulator plots in the Black Creek Watershed. On the average, only 1.2 percent and 5 percent of the total particulate nitrogen was present as exchangeable ammonium in runoff from unfertilized and fertilized plots, respectively. Due to sedimentation and to the relative stability of particulate organic nitrogen compounds, sediment nitrogen would not be expected to represent an important source of available nitrogen (ammonium or nitrate) in downstream ecosystems, particularly when compared with soluble nitrogen sources calculated according to the above scheme.

Dissolved Color

Estimates of dissolved color losses are required to provide partial bases for estimating transparency and chlorophyll-a levels in downstream impoundments. Of the components modeled in the watershed/impoundment system, color is based upon the least amount of data and/or established principles. The framework discussed below is quite theoretical and should be considered tentative until data are located for calibration and testing.

The presence of color in natural waters has often been attributed to humic acids of soil origin (Wetzel, 1975). Estimates of dissolved color in runoff are made here based upon computed sediment organic matter content and assuming a linear adsorption isotherm between the solid, organic matter phase and the dissolved color phase. Following the development for phosphorus, the average surface soil organic matter content is computed from the baseline organic matter contents of the various soil size fractions:

$$O^o = X^S_{CL}\, O^o_{CL} + X^S_{SI}\, O^o_{SI} + X^S_{SA}\, O^o_{SA} \quad (30)$$

where

O^o = baseline organic matter content of surface soil (g/kg)

O^o_{CL}, O^o_{SI}, O^o_{SA} = baseline organic matter contents of clay, silt, and sand fractions (g/kg)

Following equation (16), the increase in surface organic matter content due to tillage depth and crop residue addition is estimated from:

$$\Delta O = \frac{RES_o}{Z_T \rho_S K_8} \quad (31)$$

where

ΔO = change in surface soil organic matter content (g/kg)

RES_o = residue organic matter returned to soil surface (g/m^2-year)

Z_T = tillage depth (m)

ρ_S = soil density = 1300 kg/m^3

K_8 = an empirical parameter (year)$^{-1}$

Inclusion of this term permits consideration of the enriching effects of minimum tillage methods on surface soil organic matter levels. A K_8 value of .5 year^{-1} has been assumed. For continuous corn, this gives computed increases in O^o ranging from 64 percent to 275 percent when minimum tillage is used rather than conventional tillage in the various Black Creek soils. Residue organic matter and residue phosphorus are assumed to be related by:

$$RES_O = 500\ RES_P \tag{32}$$

This assumes that crop residues are .2 percent phosphorus, a typical value for corn (USEPA/USDA, 1975).

Assuming that the organic matter content of each size fraction is increased proportionately, the average organic matter content of eroded sediment is estimated as:

$$O^E = (X^E_{CL}\ O^o_{CL} + X^E_{SI}\ O^o_{SI} + X^o_{SA}\ O^o_{SA})\ (1 + \frac{\Delta O}{O^o}) \tag{33}$$

where

O^E = average organic matter content of eroded sediment (g/kg).

In order to estimate the concentration of dissolved color in surface runoff, a linear adsorption isotherm is assumed:

$$CO_R = \frac{O^E}{\gamma_C} \tag{34}$$

where

CO_R = dissolved color in surface runoff (m^{-1});

γ_C = organic matter/color distribution coefficient (g/kg)/m^{-1}.

Dissolved color is expressed here in units of the visible light extinction coefficient, meters^{-1}. Based upon the relationships discussed in the impoundment section, 1 m^{-1} is approximately equivalent to 200 units of Platinum-Cobalt color. Independent data for estimating the distribution coefficient, γ_c, have not been located. For an assumed γ_c value of 10 (g/kg)/m^{-1} and typical field/watershed/impoundment characteristics, computed values of CO_R are within the apparent range of observed color values for impoundments (see Figure C-5, Methods for Predicting Impoundment Water Quality). While this assumed value may be satisfactory for a preliminary analysis, more data are needed to test the assumed functional forms and parameter estimates for computing dissolved color levels.

The average color concentration entering the downstream impoundment is computed from:

$$C_{ic} = q_R \, CO_R / q \tag{35}$$

where

C_{ic} = average dissolved color level in waters entering the impoundment (m^{-1}).

This assumes that the color content of subsurface drainage is negligible, because it is in equilibrium with lower soil horizons which are relatively deficient in organic matter.

Calibration of Models for Practice Evaluations

The models described above have been calibrated for use on three soil/field types characteristic of the Black Creek Watershed, Indiana.

Table B-3 summarizes the soil-specific parameter estimates and their sources, most of which are self-explanatory. The q_R^o estimates for the various soil types are based upon the simulations performed by Woolhiser (1976, 1977), as discussed previously. Literature values of F_D, the fraction of excess nitrogen which is denitrified, range from .25 (Onishi, et al, 1974) to .80 (Huber, et al, 1977). Better drained soils would be expected to have lower denitrification rates due to increased leaching and increased soil aeration. F_D values of .5, .6, and .7 have been assumed for the ridge, upland, and lowland soils, respectively.

The models have also been calibrated for evaluation of eleven modes of farm operation on each of the three soil types. Parameter values are summarized in Tables B-4, B-5, and B-6. Each mode of farm operation is defined by a rotation, tillage method, and terracing scheme. Parameter values represent the averages over the various crop rotations.

Instead of adjusting L (length of slope), P (practice factor) is used to adjust the gross erosion rate when a terracing system is employed. Installation of one terrace per field in practices 9 to 11 effectively reduces the length of slope by 1/2 and the gross erosion rate by a factor of $1/\sqrt{2}$.

Estimates of cropping factors have been obtained from a generalized table in Volume I of U.S. EPA/USDA (1975). According to Wischmeier and Smith (1972), these values should be calculated for the Black Creek region using the seasonal distributions of soil cover and rainfall erosivity appropriate for the individual practices and for that region.

Table B-3

FIELD/SOIL PARAMETER VALUES

PARAMETER	EQUATION	SOIL TYPE LOWLAND	 RIDGE	 UPLAND	REFERENCE
Origin	-	lake plain	beach	glacial till	a,b
Name	-	Hoytville	Haskins	Morley	a,b
Texture	-	siltyclay	loam	clayloam	a,b
Hydrologic Soil Group	-	D	B	C	d
X^S_{CL}	(3)	.43	.13	.33	a
X^S_{SI}	(6)	.42	.44	.44	a
X^S_{SA}	(4)	.15	.43	.23	a
K	(1)	.28	.37	.43	f
L	(2)	300.	300.	300.	e
g	(2)	.5	2.	5.	a
P^O_{CL}	(16)	.166	.155	.016	b
P^O_{SI}	(16)	.102	.036	.011	b
P^O_{SA}	(16)	.049	.029	.011	b
q^o_R	(14)	.178	.064	.127	g
γ_P	(24)	1.0	1.0	.50	a
F_D	(29)	.7	.5	.6	g
C_D	(23)	.03	.03	.03	e
O^c_{CL}	(30)	89.3	88.1	43.30	b,c
O^o_{SI}	(30)	35.9	14.2	16.70	b,c
O^o_{SA}	(30)	8.48	3.32	4.50	b,c

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a - Table 7.11, Sommers et al (1975)

b - Table 7.18, Sommers et al (1975)

c - Assuming Organic matter/total nitrogen = 20, MRI, (1976)

d - SCS, USDA (1971)

e - Assumed value

f - SCS, USDA (1977) Figure 2.2 Lake and Morrison.

g - Discussed in text.

Table B-4

Practice Parameter Values for Lowland Soil

Parameter Equation Practice*		P (1)	C (1)	Z_T (17)	F_P (17)	F_{RES} (26)	RES_P (26)	f_R (14)
1	CC-CV	1.00	.42	.18	1.96	1.0	1.57	0
2	CC-CH	1.00	.19	.09	1.96	0.5	1.57	0
3	CC-NT	1.00	.11	.025	1.96	0.0	1.25	0
4	CB-CV	1.00	.43	.18	1.22	1.0	1.02	0
5	CB-CH	1.00	.24	.09	1.22	0.5	1.00	0
6	CB-NT	1.00	.18	.025	1.22	0.0	.90	0
7	CBWM	1.00	.068	.0	1.10	0.14	.65	.20
8	CBWM-NT	1.00	.043	.025	1.10	0.0	.63	.20
9	CC-CV-T	0.71	.42	.18	1.96	1.0	1.66	0
10	CC-CH-T	0.71	.19	.09	1.96	0.5	1.66	0
11	CB-NT-T	0.71	.18	.025	1.22	0.0	.96	0

* CC = Continuous Corn
CB = Corn/Bean Rotation
CBWM = Corn/Bean/Wheat/Meadow Rotation
CV = Conventional Tillage, fall plow
CH = Chisel Plow
NT = No-Till
T = Terraced

Table B-5

Practice Parameter Values for Ridge Soil

Parameter Equation Practice		P (1)	C (1)	Z_T (17)	F_P (17)	F_{RES} (26)	RES_P (26)	f_R (14)
1	CC-CV	1.0	.42	.18	1.96	1.0	1.57	0.
2	CC-CH	1.0	.19	.09	1.96	0.5	1.57	.35
3	CC-NT	1.0	.11	.025	1.96	0.0	1.57	.70
4	CB-CV	1.0	.43	.18	1.22	1.0	1.02	0.
5	CB-CH	1.0	.24	.09	1.22	0.5	1.02	.35
6	CB-NT	1.0	.18	.025	1.22	0.0	1.01	.70
7	CBWM	1.0	.068	.04	1.10	.14	.66	.65
8	CBWM-NT	1.0	.043	.025	1.10	0.0	.66	.80
9	CC-CV-T	.71	.42	.18	1.96	1.0	1.66	0.
10	CC-CH-T	.71	.19	.09	1.96	0.5	1.66	.35
11	CB-NT-T	.71	.18	.025	1.22	0.0	1.07	.70

For the purposes of this project, however, regionalization would have little influence on the relative or absolute evaluations of the practices considered.

Z_T values of .18, .09, and .025 m have been assumed for conventional (moldboard) plowing, chisel plowing, and no-till systems, respectively. While chisel plows may penetrate soils to the same depths as moldboard plows, the fact that they incorporate roughly one half of the surface crop residues suggests that they cover one half of

TABLE B-6

Practice Parameter Values for Upland Soil

Parameter Equation Practice		P (1)	C (1)	Z_T (17)	F_P (17)	F_{RES} (26)	RES_P (26)	f_R (14)
1	CC-CV	1.00	.42	.18	2.15	1.0	1.28	0.
2	CC-CH	1.00	.19	.09	2.15	0.5	1.28	.17
3	CC-NT	1.00	.11	.025	2.15	0.0	1.21	.35
4	CB-CV	1.00	.43	.18	1.34	1.0	.81	0.
5	CB-CH	1.00	.24	.09	1.34	0.5	.81	.17
6	CB-NT	1.00	.18	.025	1.34	0.0	.80	.35
7	CBWM	1.00	.068	.040	1.21	.16	.55	.40
8	CBWM-NT	1.00	.043	.025	1.21	0.	.55	.43
9	CC-CV-T	.71	.42	.18	2.15	1.0	1.35	0.
10	CC-CH-T	.71	.19	.09	2.15	.5	1.35	.17
11	CB-NT-T	.71	.18	.025	1.34	0.0	.85	.35

the surface area. Accordingly, an effective Z_T value of .09 m is assumed for chisel plowing. For minimum tillage, a value of .025 m or 1 inch is assumed to represent the effects of natural mixing processes in the soil (e.g., diffusion, earthworms, wind). Practice 7 consists of a corn-bean-wheat-meadow rotation, with minimum tillage, except for the fall preceding corn, in which conventional tillage is used. The average Z_T value for this rotation has been selected so that F_P/Z_T is equal to the average ratio over the four-year rotation (see equation (17)).

The phosphorus in crop residues, RES_p, is estimated from the assumed crop yields and residue phosphorus equivalents presented in Table B-7. Conventional, chisel, and no-till systems are assumed to incorporate 100 percent, 50 percent, and 0 percent of crop residues into the soil after harvest, respectively. The values of F_{RES} for Practices 7 and 8 have been selected so that computed values of RES_P $(1 - F_{RES})$ are equal to the respective averages of these products over the four-year rotations (see equation (26)).

The runoff reduction factors, f_R, are estimated for each soil type and practice using the methodology described previously (see Surface Runoff and Percolation). Soil types are important in determining the response of runoff rate to tillage methods. In soils subject to compaction or with low internal permeability (e.g., lowland), minimum tillage methods may not influence or actually cause increases in runoff rates (Mannering, 1977). In well-drained soils (e.g., ridge) however, substantial runoff reduction can be expected when minimum tillage methods are employed. The f_R values in Tables B-4, B-5, and B-6 have been estimated assuming that the ridge, upland, and lowland soils respond well, moderately and not at all, respectively, to reduced tillage.

The nitrogen budgets for all soil groups and practices are summarized in Tables B-8, B-9, and B-10. The terms correspond to those in equation (28). Nitrogen equivalents of crop yields have been estimated using the coefficients in Table B-7. Using the methods described previously (see Soluble Nitrogen), the mineralization term is estimated at 4.2 gN/m^2-year. For a typical soil organic nitrogen content of 120 g/kg and a plow depth of seven inches, this mineralization rate corresponds to a decay rate of about 1.5 percent per year, within the range of reported values for soil humus, 1 to 4 percent per year (Buckman and Brady, 1960). This rate is assumed to be constant for all row crops and soil types evaluated. In rotations, it is assumed to be zero during meadow years. The final columns in Tables B-8 through B-10 represent the net nitrogen inputs, which are used, along with F_D values, to estimate soluble nitrogen losses in surface runoff and drainage.

Some evidence of "ground truth" can be developed by comparing the computed unit emission rates of various components with those measured in streams draining the Black Creek Watershed. Two automated stations equipped for storm event sampling have been maintained on the watershed by Purdue University since 1975. The characteristics of the drainage

Table B-7

Assumed Crop Parameters for Nitrogen Budget and Residue Computations[b]

Factor	Corn	Bean	Wheat	Hay[a]
Lbs. Yield P/bushel yield	.16	.36	.28	4.5
Lbs. Yield N/bushel yield	.90	3.56	1.30	40.0
Tons residue/bushel yield	.030	.022	.030	.18
Lbs. residue P/bushel yield	.11	.089	.040	.80

[a] Hay yield units in tons instead of bushels.

[b] USEPA/USDA Volume 1 (1975).

Table B-8

Nitrogen Budgets for Lowland Soil

		Term (Equation (28)), (gN(m^2-year)					
Practice		$\dot{N}_{FX}$	+ $\dot{N}_{FE}$	+ $\dot{N}_{R}$	+ $\dot{N}_{M}$	− $\dot{N}_{Y}$	= $\dot{N}_{D}+\dot{N}_{L}$
1	CC-CV	0.0	17.60	.30	4.20	12.87	9.23
2	CC-CH	0.0	17.60	.30	4.20	12.87	9.23
3	CC-NT	0.0	19.36	.30	4.20	10.30	13.56
4	CB-CV	8.38	8.25	.30	4.20	14.60	6.53
5	CB-CH	7.60	8.25	.30	4.20	13.82	6.53
6	CB-NT	6.82	9.08	.30	4.20	12.35	8.05
7	CBWM	8.91	4.68	.30	3.15	12.68	4.66
8	CBWM-NT	8.91	4.98	.30	3.15	12.51	4.83
9	CC-CV-T	0.0	17.60	.30	4.20	13.56	8.54
10	CC-CH-T	0.0	17.60	.30	4.20	13.56	8.54
11	CB-NT-T	7.21	9.08	.30	4.20	13.09	7.70

$\dot{N}_{FX}$ = Nitrogen fixation rate (gN/m^2-yr)

$\dot{N}_{FE}$ = Nitrogen fertilization rate (gN/m^2-yr)

$\dot{N}_{R}$ = Nitrogen input in precipitation (gN/m^2-yr)

$\dot{N}_{M}$ = Nitrogen input due to mineralization of soil organic N (gN/m^2-yr)

$\dot{N}_{Y}$ = Nitrogen removal in crop yield (gN/m^2-yr)

$\dot{N}_{D}+\dot{N}_{L}$ = Net nitrogen excess = denitrification rate + loss rate (gN/m^2-yr) areas above these stations are presented and compared with the characteristics of the entire watershed in Table B-11. Nelson (1977) has provided preliminary data on the average flux rates of various components at each station over each of two sampling years, 1975 and 1976. For each station, year, and component, the contribution of septic tank effluent estimated by Nelson has been subtracted from the reported total flux.

Table B-9

Nitrogen Budget for Ridge Soil

Practice		Term (Equation (28)), (gN/m^2-year)					
		$\dot{N}_{FX}$ +	$\dot{N}_{FE}$ +	$\dot{N}_R$ +	$\dot{N}_M$ −	$\dot{N}_Y$ =	$\dot{N}_D+\dot{N}_L$
1	CC-CV	0.0	17.60	.30	4.20	12.87	9.23
2	CC-CH	0.0	17.60	.30	4.20	12.87	9.23
3	CC-NT	0.0	19.36	.30	4.20	12.87	10.99
4	CB-CV	8.38	8.25	.30	4.20	14.60	6.53
5	CB-CH	8.38	8.25	.30	4.20	14.60	6.53
6	CB-NT	7.99	9.08	.30	4.20	14.20	7.37
7	CBWM	9.49	4.68	.30	3.15	13.27	4.35
8	CBWM-NT	9.49	4.98	.30	3.15	13.27	4.35
9	CC-CV-T	0.0	17.60	.30	4.20	13.56	8.54
10	CC-CH-T	0.0	17.60	.30	4.20	13.56	8.54
11	CB-NT-T	8.38	9.08	.30	4.20	14.94	7.02

The ranges of observed fluxes are compared with the ranges of estimated unit emission rates for various soil types and practices in Table B-12. The soil types include lowland (lake plain), ridge (beach), and upland (glacial till), while the practices include a corn-bean rotation with conventional tillage (Practice 4 in Table B-4) and a corn-bean-wheat-meadow rotation with minimum tillage, except for the year preceding corn (Practice 7 in Table B-4). The former is the dominant form of row cropping in the watershed. The two practices generally reflect the upper

Table B-10

Nitrogen Budgets for Upland Soil

Practice		Term (Equation (28)), (gN/m^2-year)					
		$\dot{N}_{FX}$	$\dot{N}_{FE}$	$\dot{N}_R$	$\dot{N}_M$	$\dot{N}_Y$	$\dot{N}_D+\dot{N}_L$
1	CC-CV	0.0	13.75	.30	4.20	10.40	7.85
2	CC-CH	0.0	13.75	.30	4.20	10.40	7.85
3	CC-NT	0.0	15.13	.30	4.20	9.88	9.75
4	CB-CV	6.42	6.33	.30	4.20	11.33	5.92
5	CB-CH	6.42	6.33	.30	4.20	11.33	5.92
6	CB-NT	5.84	6.96	.30	4.20	10.75	6.55
7	CBWM	7.87	3.72	.30	3.15	10.97	4.07
8	CBWM-NT	7.87	3.92	.30	3.15	10.97	4.27
9	CC-CV-T	0.0	13.75	.30	4.20	11.09	7.16
10	CC-CH-T	0.0	13.75	.30	4.20	11.09	7.16
11	CC-NT-T	6.23	6.96	.30	4.20	11.48	6.21

Table B-11

Characteristics of Drainage Areas Above Sampling Stations in the Black Creek Watershed (Nelson, 1977)

	Location		
	Site 2	Site 6	Entire Watershed
Area (hectares)	942	714	4950
Soil Types			
Lake Plain and Beach (Lowland and Ridge)	71%	26%	64%
Glacial Till (Upland)	29%	74%	36%
Land Use			
Row Crop	63%	40%	58%
Small Grain and Pasture	26%	44%	31%
Woods	8%	4%	6%
Urban	3%	12%	5%

and lower limits, respectively, of the computed flux rates for the various practices evaluated on each soil type.

As shown in Table B-12, year-to-year differences in the observed fluxes are large. It would be impossible to obtain reliable estimates of the long-term average fluxes of these components based only upon data from two years of sampling. Because of this variability and because of the distributions of land use, field characteristics, and cropping practices in the watersheds, direct quantitative comparisons of the observed and computed fluxes are not feasible. The ranges of observed fluxes in Table B-12 correspond at least semi-quantitatively to the ranges of calculated unit emissions rates for various soil types and practices.

TABLE B-12. COMPARISONS OF OBSERVED AND ESTIMATED FLUXES OF VARIOUS COMPONENTS FROM THE BLACK CREEK WATERSHED

Component Losses (kg/ha-yr)	Observed[c]						Estimated[f]							
	Site 2[d]		Site 6[d]		Range		Lowland		Ridge		Upland		Range	
	1975	1976	1975	1976	Min.	Max.	CB-CV	CBWM	CB-CV	CBWM	CB-CV	CBWM	Min.	Max.
Delivered Sediment	2126	636	3725	353	353	3725	1104	188	2459	458	7553	1301	188	7553
Soluble Phosphorus	.20	.05	.32	.07	.05	.32	.27	.32	.10	.15	.08	.14	.08	.32
Available Sediment Phosphorus	.35[a]	.06[a]	.19[b]	.02[b]	.02	.35	.16	.03	.21	.06	.13	.04	.03	.21
Total Phosphorus	.55[a]	.11[a]	.51[b]	.09[b]	.09	.55	.43	.35	.31	.21	.21	.18	.18	.43
Soluble Nitrogen	21.0	6.1	15.2	2.8	2.8	21.0	19.6	14.0	32.8	21.7	23.7	16.2	14.0	32.8
Total Flow (m/yr)	(.29[e])	(.12)	(.26)	(.10)	(.10)	(.29)	.25	.25	.25	.25	.25	.25	.25	.25
Surface Runoff (m/yr)	-	-	-	-	-	-	.18	.14	.06	.02	.13	.07	.07	.18

[a] Assuming available sediment P/Total Sediment P = .069 ratio for average soil type in subwatershed

[b] Assuming available sediment P/Total Sediment P = .044 ratio for average soil type in subwatershed

[c] Septic tank contributions estimated by Nelson (1977) have been subtracted from the total measured loadings.

[d] For site characteristics, see Table 11.

[e] Total flow measurements may not reflect all of groundwater contributions

[f] CB-CV = corn-bean rotation with conventional tillage; CBWM = corn-bean-wheat-meadow rotation with minimum tillage except year preceeding corn.

The range of computed soluble nitrogen export (14 - 32.8 kg/ha-yr) appears to be somewhat high, compared with the observed range (2.8 to 21 kg/ha-yr). The extent to which all of the groundwater contributions are reflected in the reported measurements is unclear however, since some of the groundwater contributions may emerge further downstream in Black Creek or in the Maumee River. Since groundwater is an important transport medium for nitrate, the observed nitrogen export values may be biased on the low side. Alternatively, the assumed denitrification rates could be under-estimated, or soil nitrogen mineralization rates, over-estimated.

While the comparisons in Table B-12 do not "verify" the methodology or calibration, they suggest, minimally, that the estimates are not off by more than an order of magnitude.

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Appendix C

Methods for Predicting Impoundment Water Quality

Introduction

The models described below have been developed for use in assessing the impacts of agricultural practices on impoundment water quality. They are of an empirical nature and are designed to predict steady-state conditions in impoundments with regard to the following water quality components:

(1) sediment concentrations and trapping rates;

(2) total phosphorus concentrations and trapping rates;

(3) total nitrogen concentrations and trapping rates;

(4) mean summer, Secchi Disc transparencies; and

(5) mean summer, epilimnetic chlorophyll-a concentrations.

Models are formulated for each of the above components based upon theoretical considerations and the results of previous modeling efforts. When possible, calibration is achieved through a formal parameter estimation exercise, using an appropriate data base. Models are "verified" based upon analyses of residuals, tests for parameter stability and/or use of an independent data base. In other cases, parameter estimates are derived from measurements or experiments described in the literature and are therefore more subjective. In applying these models, sensitivity analyses will help to identify which of the parameter estimates require more detailed study and evaluation.

The methods can be used to assess the sensitivities of the above water quality components to annual average input rates, or loadings, of the following substances:

(1) water;

(2) sediment (sand, silt, and clay);

(3) phosphorus (total soluble and extractable particulate);

(4) nitrogen; and

(5) color (dissolved).

Additional independent variables of importance include:

(6) mean depth; and

(7) impoundment type (reservoir vs. natural lake).

A variety of other morphometric, hydrologic, and regional factors have also been evaluated as possible independent variables, but have been found to be of relatively minor importance, at least within the three-state region in which the models have been calibrated (Ohio, Indiana, and Illinois). Due to the empirical nature of the models, use outside of this region is not suggested, unless recalibration can be achieved using an appropriate data base. Some submodels and parameter estimates are more theoretically based than others and may be more transferable to other regions. The pathways in the impoundment water quality analysis are summarized in Figure C-1.

Data Base

The primary data base used in this effort is compiled in the attached tables. The EPA's National Eutrophication Survey (1976) has provided

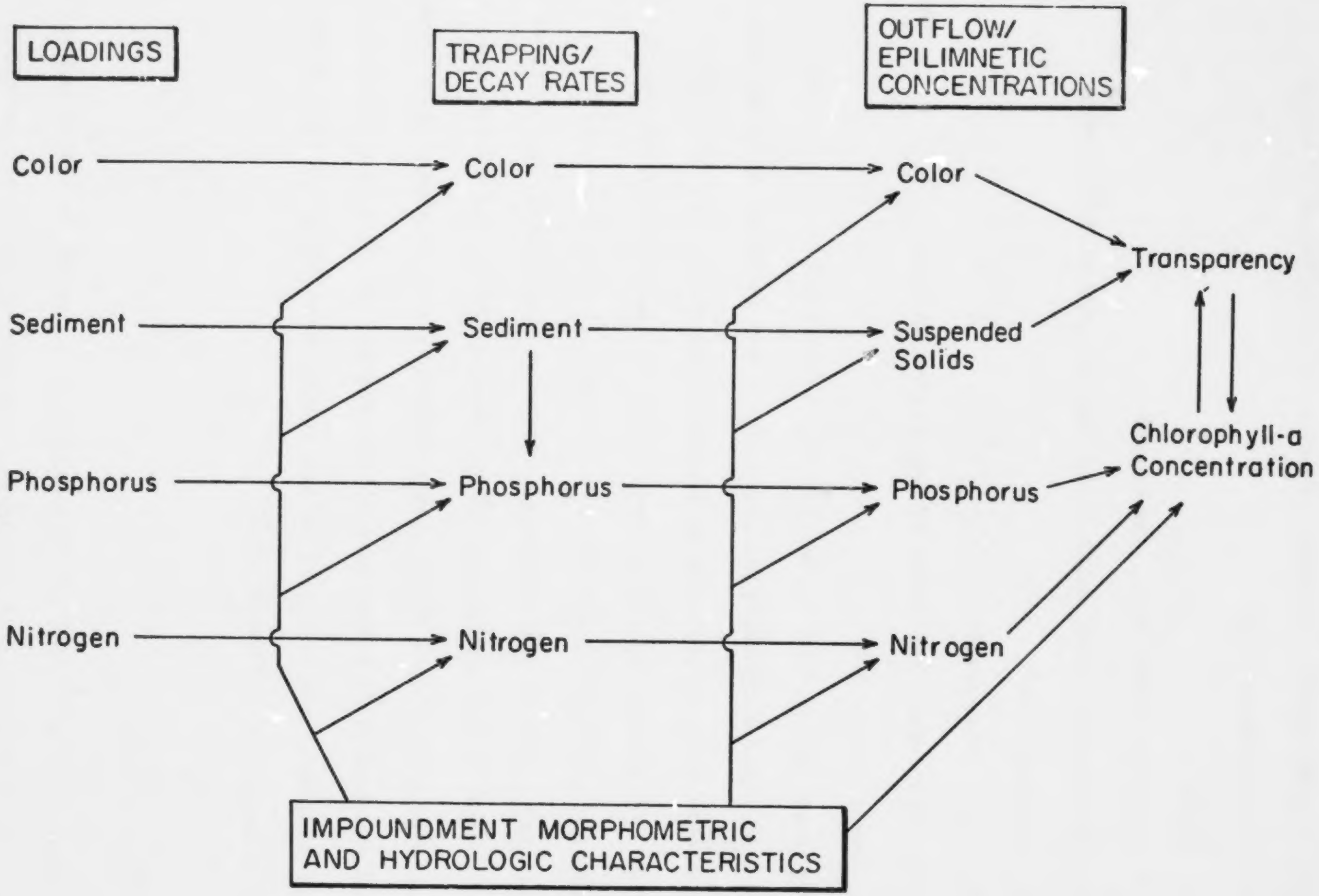
LOADINGS
TRAPPING/ DECAY RATES
OUTFLOW/ EPILIMNETIC CONCENTRATIONS
Color
Color
Color
Transparency
Sediment
Sediment
Suspended Solids
Chlorophyll-a Concentration
Phosphorus
Phosphorus
Phosphorus
Nitrogen
Nitrogen
Nitrogen
IMPOUNDMENT MORPHOMETRIC AND HYDROLOGIC CHARACTERISTICS

Figure C-1. Pathways in Predicting Impoundment Water Quality the following types of information for each of fifty impoundments in the Ohio-Indiana-Illinois region:

(1) location (state, latitude, longitude);

(2) hydrology (average outflow rate);

(3) morphometry (volume, surface area, drainage area, mean depth, maximum depth);

(4) total nitrogen and total phosphorous budgets (annual input, output, and retention rates); and

(5) trophic state indicators (mean summer chlorophyll-a and transparency).

The National Eutrophication Survey (NES) included a total of 75 impoundments in this region. The remaining 25 have been excluded from the study for one or more of the following reasons:

(1) nutrient and/or hydrologic budgets were either not determined or acknowledged by the NES as uncertain due to incomplete tributary and point source sampling program designs;

(2) mean depths were less than one meter;

(3) mean hydraulic residence times were less than 3 days;

(4) surface overflow rates were greater than 150 m/year; and/or

(5) other, unusual factors may have influenced nutrient dynamics; (e.g., Lake Sangchris Illinois has not been included because it is mixed via power plant cooling operations).

An additional data set of 20 impoundments has been compiled from those rejected above and from NES impoundments in Iowa. These data, considered of lower quality, have been used as a partial basis for verification of the chlorophyll model.

Sedimentation rate data for fifteen of these impoundments have also been obtained primarily from the USDA (1969). Additional sources of water quality data, used for calibrating the optical component submodels, include the U.S. Army Corps of Engineers (1977), Illinois State Water Survey (1977), and the Indiana State Board of Health (1976).

Sedimentation

Curves developed empirically by Bruyne (1953) are used to predict the sediment trapping efficiency of an impoundment as a function of mean hydraulic residence time, T (years). The latter is equivalent to Bruyne's "Capacity to Average Annual Inflow Ratio." The trap efficiency, R_s, is defined as the fraction of influent sediment which is deposited within the impoundment:

$$R_s = 1 - \frac{L^{1}_{os}}{L_{is}} \tag{1}$$

where

R_s = trapping efficiency (dimensionless);

L_{os} = average sediment outflow rate (kg/m^2-yr);

L_{is} = average sediment inflow rate (kg/m^2-yr).

Bruyne's original "envelope curves" characterizing the R_s vs. T relationship were based upon analysis of data from 38 impoundments. These curves are shown in Figure C-2, along with the following algebraic form, which is approximately equivalent:

$$R_s = \frac{K_s T}{1 + K_s T} \tag{2}$$

where

T = mean hydraulic residence time (years)

K_s = an empirical sediment decay rate parameter $(\text{year})^{-1}$.

This form essentially represents the trapping process as a first order decay reaction in a completely mixed system, characterized by a decay coefficient, K_s. Figure 2 shows that Bruyne's median curve is approximately equivalent to a K_s value of 68 year^{-1} or about .20 days^{-1}. Agreement is reasonable for impoundments with T values greater than .003 years.

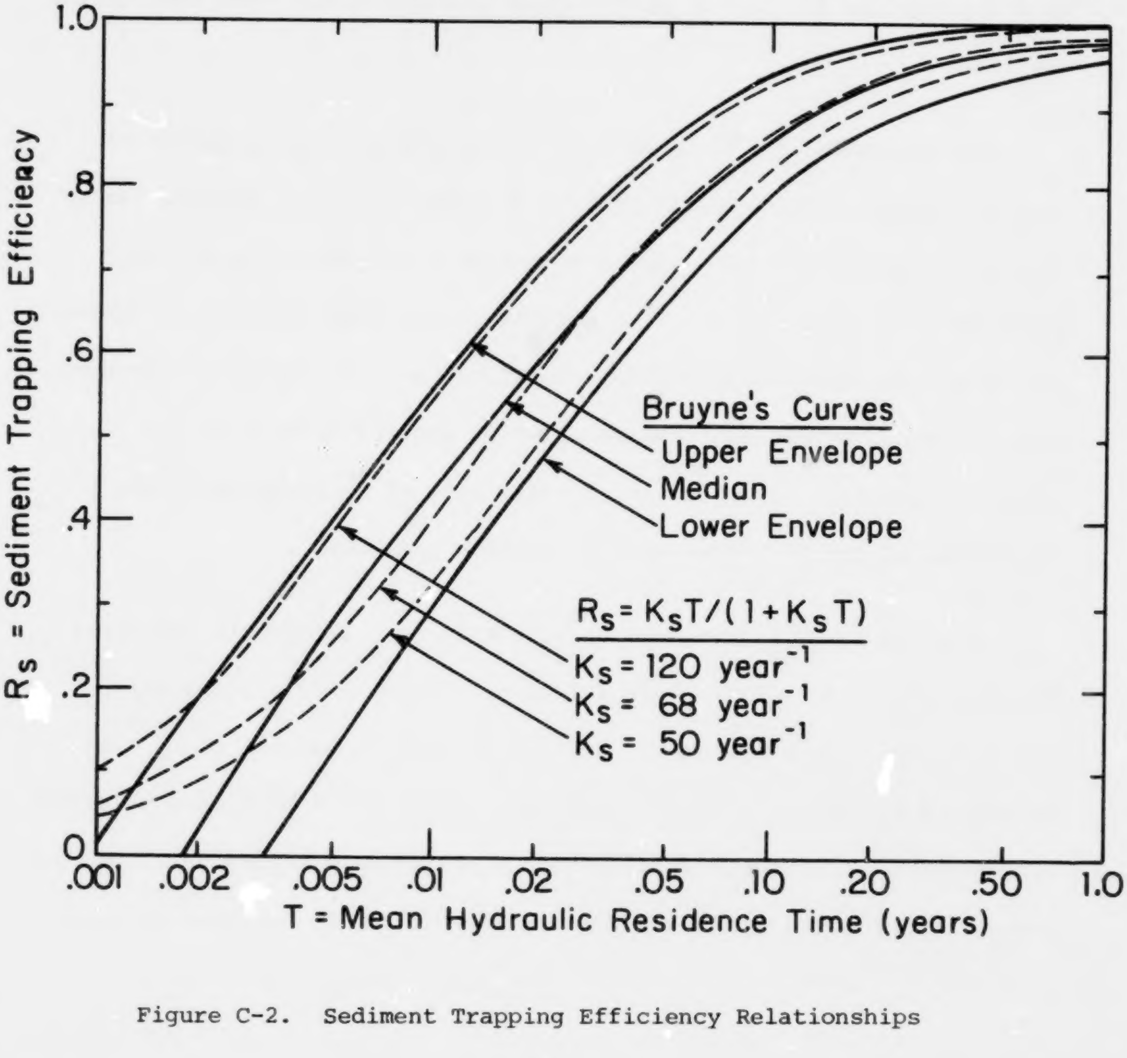

Figure C-2. Sediment Trapping Efficiency Relationships

From a theoretical point of view, a better form would represent sediment trapping as a first order settling process, in which case the decay coefficient would represent an effective settling velocity (m/year), and the independent variable would be surface overflow rate (m/year). The effects of seasonal temperature variations, flow variations, non-ideal settling behavior, particle size distribution, and particle size changes due to flocculation would render it difficult, however, to select an appropriate velocity based upon Stoke's Law. Bruyne's approach is more approrpiate for use in this context because it has been empirically verified.

Bruyne's model is modified here to account for the variation of trap efficiency with sediment texture or particle size. Smaller particles are less efficiently trapped within an impoundment due to their lower settling velocities. This results in the clay fraction of suspended solids in impoundment outflows being higher than those in impoundment inflows. Rausch and Heinemann (1975) attributed much of the observed variation in the trapping efficiency of Callahan Reservoir to variations in the clay fraction of entering sediment.

This effect is included by using a different decay rate parameter for each sediment texture class (clay, silt, and sand). Since clay and silt generally comprise the bulk of sediment loadings, decay rate parameters for clay (50 year^{-1}) and silt (120 year^{-1}) have been selected to correspond with Bruyne's lower and upper envelope curves in Figure C-2, respectively. Essentially all influent sand would be expected to be trapped. Accordingly, an arbitrarily high value of 8000 year^{-1} has been assumed for the sand decay rate.

Based upon mass balance considerations, the average suspended solids concentration in an impoundment outflow can be estimated from:

$$C_{os} = C_{is}\ (1-R_s) = \frac{C_{is}}{1 + K_s T} \tag{3}$$

$$C_{is} = L_{is}/Q_s \tag{4}$$

where,

C_{os} = outflow suspended solids concentration (kg/m^3);

C_{is} = inflow suspended solids concentration (kg/m^3);

Q_s = surface overflow rate (m/year).

Both the trapping rates and suspended solids concentrations are determined as the sum of the respective values for all texture classes.

Phosphorus Trapping and Concentration

Phosphorus is considered an important water quality variable insofar as it may control the growth of phytoplankton in an impoundment. The models for chlorophyll concentration and transparency developed in subsequent sections rely upon predictions of C_{op}, the average outflow total phosophorus concentration. C_{op} estimates are developed from average inflow phosphorus concentrations and a retention model. As in the case of sediments, the retention model predicts the fraction of influent phosphorus which is trapped in the lake sediments as a result of various physical, chemical, and biological reactions occurring in the water column. (Dillon, 1974). A retention model is formulated and calibrated for Cornbelt impoundments below.

A previous analysis of data from north central and northeastern U.S. impoundments (Walker, 1977) suggested that a model of the following form would be appropriate for predicting phosphorus retention coefficients:

$$1 - R_p = \frac{C_{op}}{C_{ip}} = \frac{1}{1 + K_p T} \qquad (5)$$

$$K_p = b_0 \, Q_s^{b_1} \, Z^{b_2} \qquad (6)$$

where,

R_p = retention coefficient for total phosphorus (dimensionless)

C_{op} = average outflow total P concentration (g/m^3)

C_{ip} = average inflow total P concentration (g/m^3)

K_p = effective first order decay coefficient for total P $(year)^{-1}$

Z = mean depth (m)

Q_s = surface overflow rate = Z/T (m/year)

b_0, b_1, b_2 = empirical parameters.

This essentially represents phosphorus trapping as a first order decay process in a mixed system, with the decay rate allowed to vary with Q_s and Z according to equation (6). The latter dependences were included to allow for possible effects of incomplete mixing or other factors related to depth and overflow rate. Best estimates of the empirical parameters b_0, b_1, and b_2 for lakes north of 42° latitude suggested the following model:

$$K_p = .82 \; \frac{Z}{Q_s}^{-.55} = .82 \; T^{-.55} \tag{7}$$

$$1 - R_p = \frac{1}{1 + .82 \; T^{.45}} \tag{8}$$

Equation (8) explained 78 percent of the variance in the reported retention coefficient data for 105 impoundments (Walker, 1977). Similar models have been developed independently by Larsen and Mercier (1975) and by Vollenweider (1976), for lakes in the same latitude range.

Figure C-3 demonstrates that the trapping efficiencies of most of the impoundments in the Ohio-Indiana-Illinois region are considerably higher than those predicted by equation (8). Accordingly, a more general form of the above model has been tested for these impoundments:

$$1 - R_p = \frac{1}{1 + a_0 \; Q_s^{a_1} Z^{a_2} C_{ip}^{a_3}} \tag{9}$$

An equivalent form of equation (9) is appropriate for a log-linear regression analysis:

$$\frac{R_p}{1 - R_p} = a_0 \; Q_s^{a_1} Z^{a_2} C_{ip}^{a_3} \tag{10}$$

$a_o = 1.986$

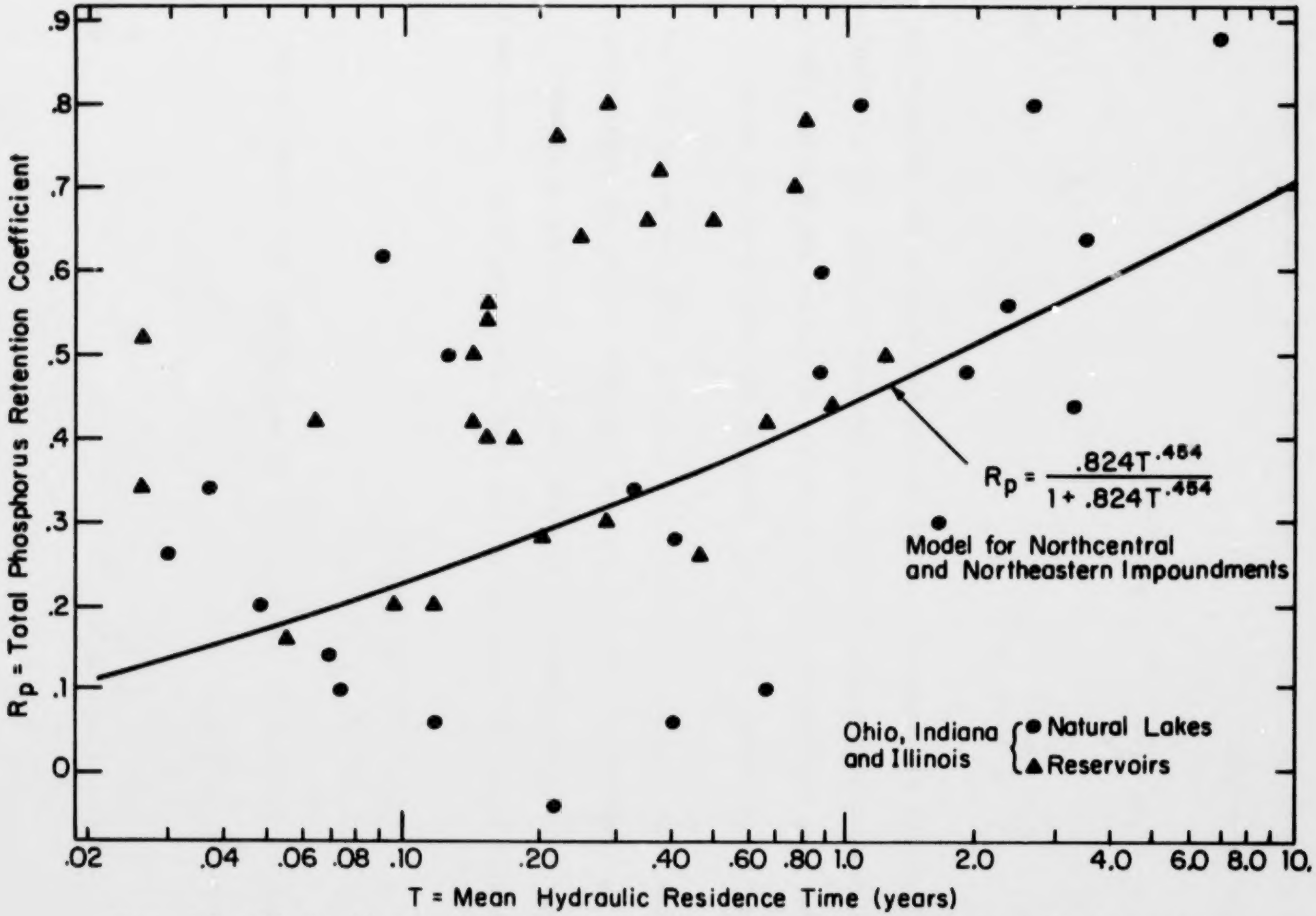

Figure C-3. Relationship between Total Phosphorus Retention Coefficient and Mean Hydraulic Residence Time

$a_1 = -.309 \pm .101$

$a_2 = .805 \pm .240$

$a_3 = .621 \pm .185$

All coefficients are significant at the 95 percent confidence level, but equation (10) explains only 36 percent of the variance in $\log_{10} (R_p/(1-R_p))$. This is a low level of predictive ability, relative to that demonstrated by equation (8) for northern lakes. This suggests that other factors may be controlling phosphorus trapping in Corn Belt impoundments and/or that these data are of poor quality relative to those used in developing equation (8). The latter explanation is considered less likely, because the data bases for both models have been derived primarily from the NES, in which consistent sampling program designs and data handling procedures were maintained.

In order to permit an assessment of the possible effects of sedimentation on phosphorus trapping, sedimentation rates for 15 of the NES lakes have been obtained from a national data summary published by the USDA (1969) and from local studies by the Illinois State Water Survey (1977b) and the Army Corps of Engineers (1970). Effects of sedimentation have been evaluated with a modified form of equation (10):

$$\frac{R_p}{1 - R_p} = a_0 \, Q_s^{a_1} Z^{a_2} C_{ip}^{a_3} S_t^{a_4} \tag{11}$$

where, S_t = sedimentation rate (kg/m^2-lake surface-year)

$a_o = .246$

$a_1 = -.491 \pm .180$

$a_2 = .280 \pm .328$

$a_3 = .647 \pm .309$

$a_4 = 1.095 \pm .302$

For the fifteen impoundments tested, equation (11) explains 76 percent of the variance in $\log_{10}(R_p/(1-R_p))$, a marked improvement over the performance of equation (10). All of the coefficients are significantly different from zero, with the exception of the depth exponent, a_2. The relatively narrow range of mean depths in this subsample of lakes (1.2-5 meters) may have been responsible, in part, for this lack of significance.

The apparent importance of sedimentation rate as a factor influencing phosphorus trapping is indicated by the size of a_4 relative to the other exponents. Multicollinearity among the four factors tested renders it difficult to establish the relative magnitude of the various coefficients with much confidence, however. The correlation matrix of parameter estimates is presented below:

	a_1	a_2	a_3	a_4
a_1	1.00			
a_2	.31	1.00		
a_3	.37	.19	1.00	
a_4	-.76	-.51	-.34	1.00

The sedimentation coefficient, a_4, is most significantly correlated with the overflow rate exponent, a_1 ($r = -.76$). This is attributed to S_T and Q_s both being dependent upon the ratio of drainage area to surface area. The failure of Q_s to explain much of the retention coefficient variance in the larger data set indicates that S_T does have significant predictive capability, although the relative magnitudes of the coefficients a_1 and a_4 are somewhat difficult to determine from these data.

The measured sedimentation rates employed in the above regression analysis primarily reflect external loadings of sediment from the respective watersheds, as opposed to sediment generated within the impoundments as a result of primary production and chemical precipitation. The reported S_T values range from 3 to 71 kg/m^2year. The maximum rate of net primary production for temperate, eutrophic lakes reported in a data summary compiled by Wetzel (1975) corresponds to about 1.5 kg organic matter/m^2-year. Due to decay processes and respiration in the food chain, a small fraction of net production is usually sedimented. Estimates for Lawrence and Mirror Lakes are on the order of seven percent (Wetzel, 1975). Precipitation of calcium carbonate would also contribute to measured sedimentation rates. Alkalinity changes, induced by photosynthetic removal of CO_2, are on the order of .5 kg $CaCO_3/m^2$ year for eutrophic systems (Vollenweider (1968), Otsuki, et al. (1974)). Thus the reported sedimentation rates are assumed to result primarily from erosion in the respective watersheds.

Modifications of the reported phosphorus retention coefficient data have been made in order to improve the reliability of the parameter estimates. The NES phosphorus loading estimates were based upon monthly grab samples of lake tributaries. It is doubtful that these estimates reflect loadings of particulate phosphorus entering during storm events. In a study of the NES Non-Point Source Watersheds, Omernik (1976) reported that an average of 41 percent of the total phosphorus export from 96 agricultural watersheds (80 of which were in the Corn Belt region) was in the ortho-phosphorus form. This is in contrast with data derived from continuous flow-weighted composite sampling, which typically indicate less than 10 percent ortho-phosphorus (Nelson, et al., 1976). An attempt to account for unsampled, extractable, particulate phosphorus loading has been made for each of the fifteen lakes according to the following:

$$L'_p = L_p + L_s Y_{ps} \qquad (12)$$

$$R'_p = 1 - (1 - R_p) \frac{L_p}{L'_p} \qquad (13)$$

$$L_s = S_t (1 + \frac{1}{68T}) \qquad (14)$$

where,

L_p, L'_p = reported and corrected phosphorus loadings (g/m^2-year)

R_p, R'_p = reported and corrected phosphorus retention coefficients (dimensionless)

L_s = estimated external sediment loading (kg/m^2-year)

Y_{ps} = assumed extractable phosphorus content of entering sediment = .08 g/kg.

Equation (14) estimates the external sediment loading, L_s, from the reported trapping rate S_t, by employing Bruyne's trapping curve (Figure C-2). The assumed value of Y_{ps} is based upon measurements of extractable phosphorus contents of sediment measured in Black Creek rainulator studies (Sommers, et al., 1973) and in four Missouri Valley agricultural watersheds (Schumann, et al, 1973). This effort to correct the phosphorus loadings and retention coefficients reported by the NES is admittedly approximate, but is considered preferable to using the reported values directly. The reported and corrected loadings and retention coefficients are listed in attached tables. Using the corrected retention coefficient data, the parameters of equation (11) have been re-estimated:

$a_0 = .419$

$a_1 = -.757 \pm .127$

$a_2 = .236 \pm .222$

$a_3 = .077 \pm .207$

$a_4 = 1.175 \pm .205$

Since a_3, the exponent for C_{ip}, is not significantly different from zero, it has been excluded and the remaining parameters, re-estimated:

$a_0 = .377$

$a_1 = -.779 \pm .109$

$a_2 = .222 \pm .211$

$a_3 = 0$

$a_4 = 1.201 \pm .186$

With these parameter values, equation (11) explains 86 percent of the variance in the "corrected" $\log_{10}(R_p/(1-R_p))$ values and 77 percent of the variance in R_p, with a standard error of .09. Despite its low significance level, the depth coefficient (a_2) has been allowed to remain because this lack of significance may be attributed to the relatively narrow range of mean depths in the data base (1.2-5.0 meters).

The apparent importance of sedimentation rate as a factor influencing phosphorus retention is partially supported by theory and independent experimental evidence. The adsorption of phosphorus by soils and sediments has been studied extensively and is considered to involve primarily the adsorption of iron and aluminum phosphate compounds to clay particle surfaces (Syers, et al, 1972). Kunishi, et al, (1972) have observed this adsorption process to be partially irreversible. Under the anaerobic conditions typical of lake bottom sediments, iron phosphate compounds are much more soluble and equilibrium may favor the release of phosphorus into the water column. The rate of release may be severely limited, however, by kinetics (e.g., diffusion rates). Apatite formulation in calcareous sediments represents a permanent phosphorus sink (Stumm and Leckie, 1970). The empirical evidence presented above suggests that external sediment loadings do contribute to net phosphorus trapping efficiency. Thus, release of dissolved phosphorus from these lake bottoms may be small relative to adsorption/ sedimentation rates despite the fact that dissolved oxygen concentrations less than 1 g/m^3 were detected by the NES in the bottom waters of seven out of the fifteen impoundments. An important implication is that particulate phosphorus loadings may have little effect on average epilimnetic or outflow phosphorus concentrations in these types of impoundments. In fact, reductions in soil erosion could conceivably result in reductions in phosphorus trapping efficiencies and subsequent increases in average epilimnetic phosphorus levels. These relationships may not hold true for impoundments with greater mean depths, which would have more pronounced stratification and greater potential for phosphorus recycling through anaerobic bottom waters.

Additional theoretical interpretations of these results are possible with reference to the "settling velocity" model proposed by Vollenweider (1969) and Chapra and Tarapchak (1976) to predict phosphorus retention coefficients:

$$1 - R_p = \frac{Q_s}{Q_s + U} = \frac{1}{1 + U_p/Q_s} \qquad (15)$$

where,

U_p = effective settling velocity for total phosphorus (m/yr).

Vollenweider (1969) showed that a U_p value of approximately 10 m/yr was appropriate for a sample of northern temperate lakes. Comparing this formulation with equation (11) and the last set of regression coefficients shows that the settling velocity for these 15 Corn Belt impoundments can be estimated from:

$$U_p = Q_s \frac{R_p}{1 - R_p} \qquad (16)$$

$$\simeq .377\ Q_s^{.231} Z^{.222} S_t^{1.201} \qquad (17)$$

The relative magnitudes of the exponents suggest a dominant influence of S_t, the sedimentation rate.

While measured sedimentation rates were available for only 15 of the 50 impoundments included in this study, further indirect evidence can be presented for the effect of S_t on phosphorus settling velocity. One would expect lakes with large percentages of their drainage areas impounded upstream to have relatively low sedimentation rates, because of sediment trapping upstream. This, in turn, should result in lower phosphorus settling velocities, according to equation (17). Five such lakes could be identified within the original set of fifty. Table C-1 compares the measured phosphorus settling velocities (equation (18)) of these lakes with velocities measured in the lakes immediately upstream. These data indicate a consistent decreasing trend in phosphorus settling velocity moving downstream in each watershed. For example, Witmer flows into Westler, and Westler, in turn, into Dallas. The U_p values for these lakes are 16.0, 10.2, and 2.0 m/year, respectively. In addition, James Lake, the only lake in the data set with a reportedly negative phosphorus retention coefficient, has a watershed, 87 percent of which is impounded upstream. While alternative explanations are possible, these data are at least consistent with the theory that sedimentation rates partially control phosphorus trapping in these impoundments.

Equation (16) is considered rather tenuous for use as a predictive tool, because of its relatively small data base, parameter collinearity and rather empirical form. In applying the model to evaluate the water quality impacts of agricultural practices, a minimum value of 3 kg/m^2-year is assumed for S_t, since the relationship between phosphorous settling velocity and sedimentation rate has not been examined below this S_t value. Compilation of additional data from other areas of the country and testing some more theoretically formulated models would be worthwhile in the interest of further defining the relationships among

Table C-1

Phosphorus Settling Velocities in Lakes and Reservoirs with Partially Impounded Watersheds

Lake or Reservoir*	NES Number	Percent of Watershed Impounded	U_p** (m/yr)
Witmer	349	0	16.01
Westler	346	96	10.19
Dallas	326	96	1.98
Webster	345	0	16.15
James Lake	330	87	- 1.09
Olin	338	0	40.01
Oliver	339	55	6.75
Shelbyville	315	0	26.96
Carlyle	297	39	9.59

* Grouped moving downstream in each watershed (e.g. Witmer flows into Westler and, in turn, into Dallas)

** $U_p = Q_s \dfrac{R_p}{1-R_p}$ = effective phosphorus settling velocity.

phosphorus retention, sedimentation rate, hydrology, and impoundment morphometry.

Average outflow phosphorous concentrations are estimated from the average inflow concentrations and estimated retention coefficients according to the following:

$$C_{op} = C_{ip} \ (1-R_p) \qquad (18)$$

where,

C_{op} = average outflow total phosphorus concentration (g/M^3).

The outflow concentration is a good indicator of typical lake concentrations. A regression analysis of data from the 23 natural lakes in the data set suggests the following relationship:

$$C_{mp} = .935 \ C_{op}^{1.062} \qquad (19)$$

$\{R^2 = .921, \text{SEE} = .136\}$*

A similar analysis of data from 27 reservoirs yields the following:

$$C_{mp} = .605 \ C_{op}^{.887} \qquad (20)$$

$\{R^2 = .702, \text{SEE} = .139\}$*

---

* Coefficient of determination and standard error of estimate, respectively, referring to $\log_{10}$ (C_{mp}).

where,

C_{mp} = spatial and temporal median, summer total phosphorus concentration in the impoundment (g/m^3).

Note that the slope of the relationship is less for reservoirs as compared with natural lakes. This could be due to differences in hydrodynamics, particularly effects of bottom-water withdrawals from some reservoirs.

Nitrogen Trapping and Concentration

Nitrogen is considered an important water quality variable for two primary reasons. High nitrate levels are of concern with regard to drinking water quality, because of the possible toxicity. Secondly, supplies of fixed nitrogen are also required to support most types of algal growth. The development of a predictive model for nitrogen concentration is analagous to that described above in the case of phosphorus.

The impoundments sampled by the NES in the region appear to be significantly less efficient in trapping nitrogen than in trapping phosphorus, as indicated by the following regression equations:

$$R_n = -.032 + .618\ R_p \qquad \{R^2 = .40,\ SEE = .17\} \qquad (21)$$

$$U_n = .945\ U_p^{.506} \qquad \{R^2 = .25,\ SEE = .51\}^* \qquad (22)$$

---

* $\log_{10}$ statistics.

One explanation for this behavior is that nitrogen is supplied to these impoundments well in excess of phosphorus, relative to biological requirements. The ratio of geometric mean nitrogen to phosphorus loadings is 24, about three times that typical of algal biomass. Limiting nutrient bioassay studies conducted by the NES also indicate that the algae in most of these impoundments are phosphorus, as opposed to nitrogen-limited, given sufficient light.

Fixation of nitrogen by blue-green algae might also be responsible, in part, for relatively low nitrogen retention efficiency. This phenomenon is probably not very important in the context of the total nitrogen budgets, however, since reported direct measurements of N_2 fixation in aquatic systems range from 0 to .4 gN/m^2 - year (Wetzel, 1975), whereas reported external nitrogen loadings for the fifty impoundments examined here average 103 gN/m^2 - year and range from 3.3 to 597 gN/m^2 - year. The presence of high nitrate concentrations would also tend to suppress nitrogen fixation activity (Wetzel, 1975).

Another factor possibly tending to decrease nitrogen trapping efficiency is that nitrate nitrogen is not significantly adsorbed by sediments. This would tend to reduce the importance of sedimentation as a nitrogen removal mechanism, as compared with phosphorus, but may be offset, to some degree, by denitrification. This has been tested empirically by performing a regression analysis of the nitrogen retention data, using a model analogous to that employed for phosphorus (Equation 11):

$$\frac{R_n}{1-R_n} = c_o \, Q_s^{\,c_1} \, z^{\,c_2} \, C_{in}^{\,c_3} \, S_t^{\,c_4} \qquad (23)$$

$c_o = 1.928$

$c_1 = -1.155 \pm .395$

$c_2 = .262 \pm .770$

$c_3 = -.625 \pm .716$

$c_4 = .447 \pm .572$

$\{R^2 = .56, \text{SEE} = .565\}$

The sedimentation rate exponent, c_4, is not significantly different from zero, suggesting that nitrogen retention is not as strongly linked to sedimentation as is phosphorus retention. Similar conclusions are reached when alternative forms of this model are estimated, deleting the other insignificant parameters (c_2 and c_3).

The parameters of equation 23 have been re-estimated, setting $c_4 = 0$ and using a data base of 43 impoundments:*

$c_o = .223$

$c_1 = -.445 \pm .092$

$c_2 = .351 \pm .200$

$c_3 = .862 \pm .299$

$c_4 = 0$

$\{R^2 = .455, \text{SEE} = .343\}$

---

* The retention coefficients of the seven impoundments with reported value less than zero have been excluded in order to permit the regression analyses to be performed on a logarithmic scale.

Analysis of residuals from this model suggests that R_n values are underpredicted slightly (by about .12) in six out of seven lakes with nitrogen to phosphorus loading ratios less than 10. This is evidence for possible nitrogen limitation in a few of these impoundments and suggests that the above model should not be employed under nitrogen-limited conditions. Future development of this model might take into account the coupling of nitrogen and phosphorus retention mechanisms.

Average outflow total nitrogen concentrations can be estimated from the average inflow concentrations and estimated retention coefficients according to the following:

$$C_{on} = C_{in}(1-R_n) \tag{24}$$

where,

C_{on} = average outflow total nitrogen concentration (g/m^3).

With the retention parameter estimates listed above, Equation 24 explains 77 percent of the variance in $\log_{10}C_{on}$, with a standard error of .10. It is assumed that C_{on} is a reasonable indicator of average epilimnetic total nitrogen concentrations, although no data are available to substantiate this; the NES measured only inorganic nitrogen concentrations within the impoundments.

Transparency

Transparency is an important water quality variable, not only for aesthetic reasons but also because it influences the amount of light available for photosynthesis. Light penetration is considered to be an important factor regulating the die-off rates of coliform bacteria in natural aquatic systems (Chamberlin, 1978). Thus, increased transparency would also be expected to result in lower ambient levels of these organisms. Pathogenic bacteria may be similarly affected.

The Secchi disc is commonly used to measure transparency in impoundments. It can be approximately related to the light extinction coefficient in the water column with model of the following form (Vollenweider, 1974):

$$Z_s \varepsilon = k \tag{25}$$

where,

Z_s = Secchi disc transparency (m)

ε = visible light extinction coefficient (m^{-1})

k = an empirical constant.

Holmes (1970) has suggested that a k value of 1.44 is appropriate for turbid, coastal waters. Poole and Atkins (1929) suggested a value of 1.7. Simultaneous Z_s and ε measurements performed by the Indiana State Board of Health (1976) in eight impoundments have been analyzed to verify the use of Equation 25 with k = 1.66, the geometric mean value for the data set (Figure C-4). The possibility of a positive bias in this relationship at high ε values needs to be examined with additional data.

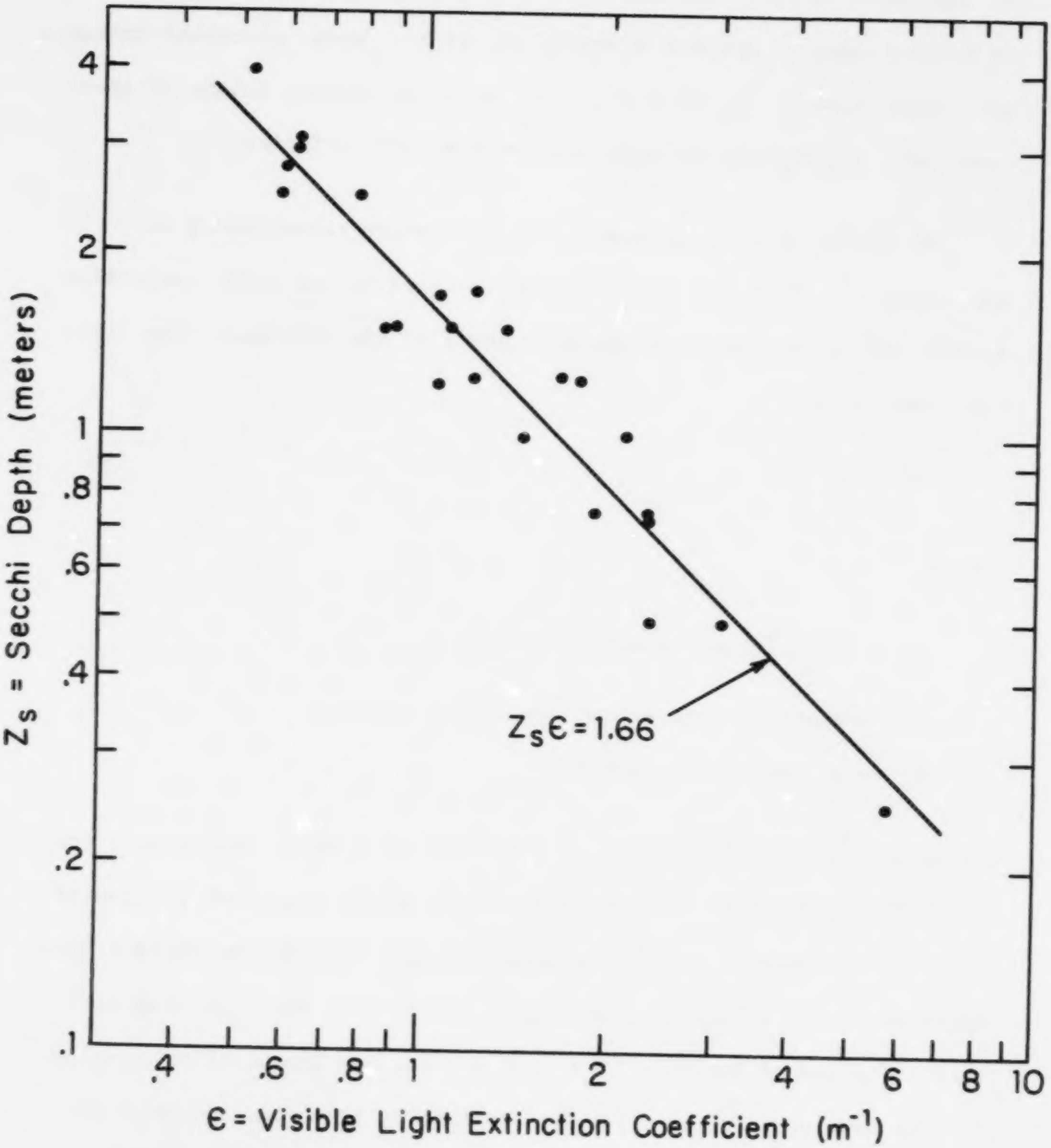

Figure C-4. Relationship between Secchi Depths and Visible Light Extinction Coefficients in Indiana Impoundments (ISBH, 1976)

The extinction coefficient, ε, represents the fraction of visible light energy absorbed per meter of depth, according to Beer's Law (Wetzel, 1975):

$$\frac{I_z}{I_o} = \exp(-\varepsilon Z) \tag{26}$$

where,

I_z = visible light intensity at depth Z (cal/cm^{2}hr)
I_o = visible light intensity at surface (cal/cm^{2}hr)

The light extinction coefficient can be approximately represented as a linear function of four components (Lassiter, 1975):

$$\varepsilon = \varepsilon_W + \varepsilon_S + \varepsilon_B + \varepsilon_C \tag{27}$$

where,

ε_W = extinction coefficient attributed to water (m^{-1})
ε_S = extinction coefficient attributed to non-living, suspended solids (m^{-1})
ε_B = extinction coefficient attributed to algal biomass (m^{-1})
ε_C = extinction coefficient attributed to dissolved color (m^{-1})

The first term, ε_W, is on the order of .04 m^{-1}, corresponding to the maximum observed Secchi depth of about 40 m (Wetzel, 1975), and is relatively insignificant in the impoundments being studied here. The following linear relationships are used to estimate the remaining three components:

$$\varepsilon_S = k_S S \tag{28}$$

$$\varepsilon_B = k_B B \tag{29}$$

$$\varepsilon_C = k_C C \tag{30}$$

where,

S = concentration of non-algal particulate material (g/m^3)

B = concentration of chlorophyll-a (g/m^3)

C = concentration of dissolved color (Pt-Cobalt Units)

k_S, k_B, k_C = empirical constants.

The calibration of three equations is discussed below.

Secchi depth and suspended solids measurements taken by the Illinois State Water Survey (1977) in the Fox Chain of Lakes, Illinois, and by the U.S. Army Corps of Engineers (1977) in five Indiana and Ohio impoundments have been used to develop an estimate for k_S. Figure C-5 shows the relationship between suspended solids concentration and the extinction coefficient (determined from reported Z_S values and Equation 25). Average values were reported for each of the Fox Chain of Lakes. Individual measurements provided by the USACE have permitted division of the data from each impoundment into two, equal-sized groups, based upon solids concentrations. The two summary points shown for each impoundment represent the median ε and S values in each group. The suspended solids concentrations reported in these studies represent both algal and non-algal particulate materials. It is assumed that the later dominate, since these data are in the range from 2 to 80 g/m^3, while algal biomass levels would not be expected to be much in excess of 5 g/m^3, assuming a maximum chlorophyll-a concentration of 100 mg/m^3. The lines drawn in Figure C-5 correspond to a k value of .085 m^2/g - suspended solids. Deviations of the data from the lines are assumed to be attributed to variations in $\varepsilon_W + \varepsilon_C$, the

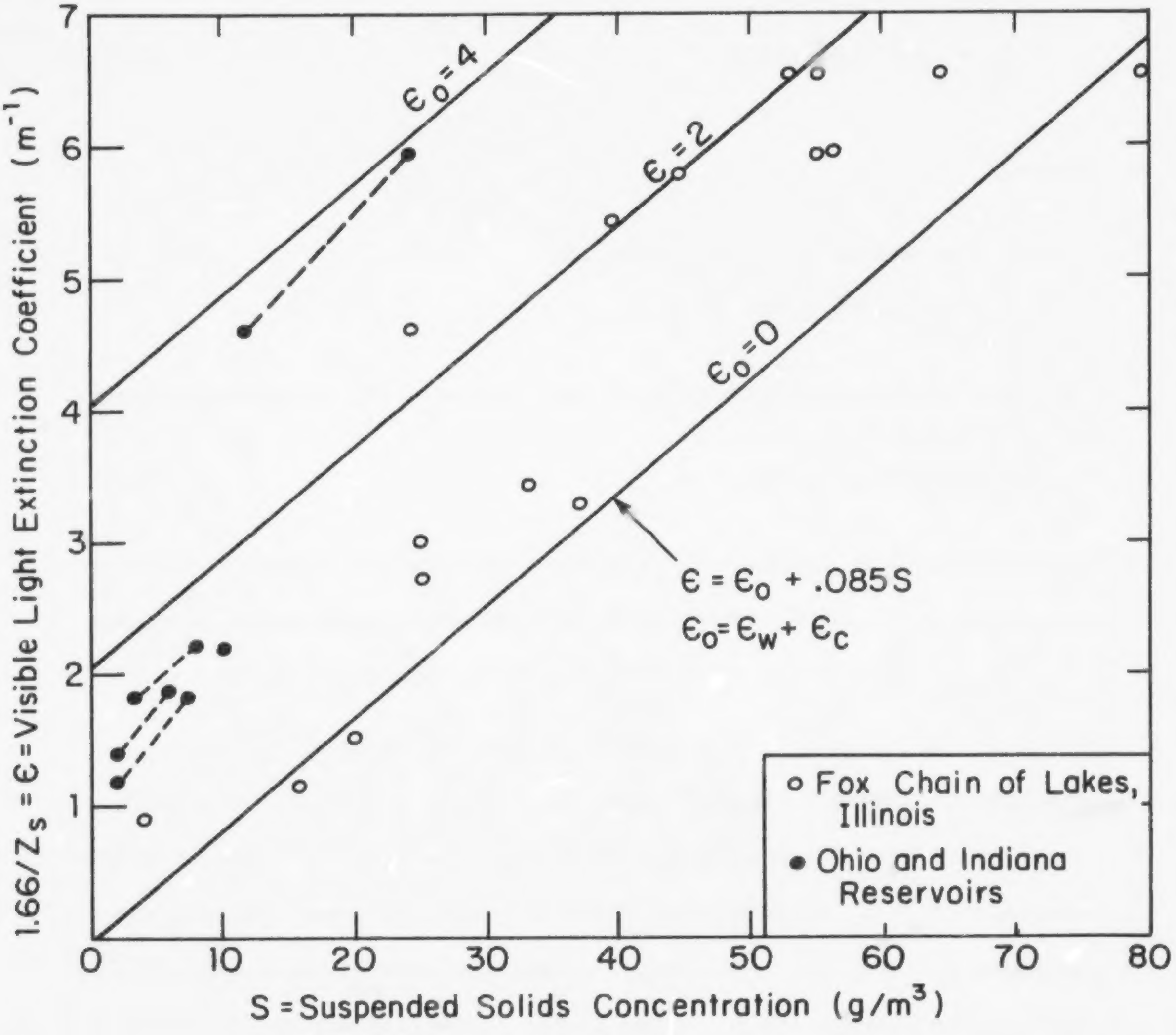

Figure C-5. Relationship between Visible Light Extinction Coefficients and Suspended Solids Concentrations in Corn Belt Impoundments water and color extinction coefficients. No independent color measurements could be located to verify this assumption.

Further support for use of a k_S value of .085 m^2/g is obtained from the results of Shannon and Brezonik (1972) who derived the following relationship for Northcentral Florida lakes:

$$\frac{1}{Z_s} = .003\ C + .152\ N \qquad (31)$$

where,

C = dissolved color (Pt-Co Units)
N = turbidity (JTU)

In terms of the extinction coefficient, equation (31) is equivalent to:

$$\varepsilon = .005\ C + .252\ N \qquad (32)$$

With reference to Equation 27, the first term is attributed to dissolved materials (ε_c), while the second is attributed to particulate materials ($\varepsilon_S + \varepsilon_B$). The average ratio of turbidity to suspended solids for the Fox Chain of Lakes is .32 JTU/(g/m^3). Thus, in terms of turbidity, a k_S value of .085 m^2/g is equivalent to .085/.32 = .266 m^{-1}/JTU, which agrees well with Shannon and Brezonik's value of .252 m^{-1}/JTU. Possible variability in k_S attributed to different particle types and size distributions (Lassiter, 1975) suggests that the assumed value of .085 m^2/g may only be appropriate for lakes in the region and not for rivers.

Calibration or verification of the color term, ε_C, cannot be achieved directly because no color data have been located for these impoundments. Shannon and Brezonik's results (Equation 32) suggest a k_C value of $.005\text{m}^{-1}$/(Pt-Co unit). Color is assumed here to represent humic acids derived from soil organic matter (Wetzel, 1975). The method for predicting color loadings based upon computed runoff rates and sediment organic matter content has been described previouslv. Within an impoundment, color can be expected to decay as a result of microbial degradation and adsorption/sedimentation processes. The removal of color is represented here as a first-order reaction, in a model similar to that employed for sedimentation:

$$C_{oc} = \frac{C_{ic}}{1+K_c T} \qquad (33)$$

where,

C_{oc} = average outflow color concentration (Pt-Co units)

C_{ic} = average inflow color concentration (Pt-Co units)

K_c = decay rate (year^{-1})

Secchi depth and suspended solids data from the upstream and downstream ends of Mississinewa Reservoir (U.S. Army Corps of Engineers, 1977) have been analyzed to develop an approximate estimate for K_c, the color decay rate parameter. For each station and sampling date, a color concentration has been estimated by employing Equations 25, 27, 28, and 30 and the parameter estimates derived above:

$$C = \frac{\varepsilon - k_S S - \varepsilon_w}{k_C} = \frac{\frac{1.66}{Z_S} - .085\ S - .040}{.005} \qquad (34)$$

Over a three-year period, the flow-weighted average inflow and outflow color concentrations have been computed as 766 and 347 Pt-Co-units, respectively. The mean hydraulic residence time over this period was about .2 years. With reference to Equation 33, these values are equivalent to a K_c value of about 6 year^{-1}.

These data suggest that color is considerably more conservative than suspended clay, the decay rate for which, according to Equation 2, is about 50 year^{-1}. The apparent color decay rate is high, however, compared with typical degradation rates of humus in soil systems, .01-.04 year^{-1} (Buckman and Brady, 1966). This suggests that adsorption/ sedimentation may be the dominant color removal mechanism as discussed by Otsuki and Wetzel (1974). More data are needed in order to further calibrate and verify the relationships developed above for color degradation and its contribution to the extinction coefficient.

The algal light extinction component ε_B, is assumed to be proportional to chlorophyll-a concentration, according to Equation 29. Riley's (1956) data from mixed, natural, marine algal populations suggest that the proportionality constant k_B, varies somewhat with chlorophyll concentration:

$$k_B = 8.8 + 5.4\ B^{-.33} \qquad (35)$$

According to this equation k_B decreases from 40 to 20 m^2/g as chlorophyll increases from .005 to .1 g/m^3. Other investigators (Lorenzen and Mitchell (1973), DiTorro, et al, (1975)) have assumed constant values of k_B within the above range. An average k_B value of 30 m^2/g is assumed here, although additional data and analysis could permit better definition of the quantitative relationship between chlorophyll-a concentration and light extinction.

The relationship between transparency and chlorophyll in the NES impoundments is shown in Figure C-6. From Equations 25, 27, and 29, the Secchi depth is given by:

$$Z_S = \frac{k}{\alpha + k_B B} = \frac{1.66}{\alpha + 30\ B} \qquad (36)$$

$$\alpha = \varepsilon_W + \varepsilon_C + \varepsilon_S \qquad (37)$$

Independent measures of the non-algal portion of the extinction coefficient, α, are not available for these impoundments. Accordingly, Equation 36 has been plotted in Figure C-6 for various assumed values of α ranging from 0 to 3. The locations of reservoirs on the plot relative

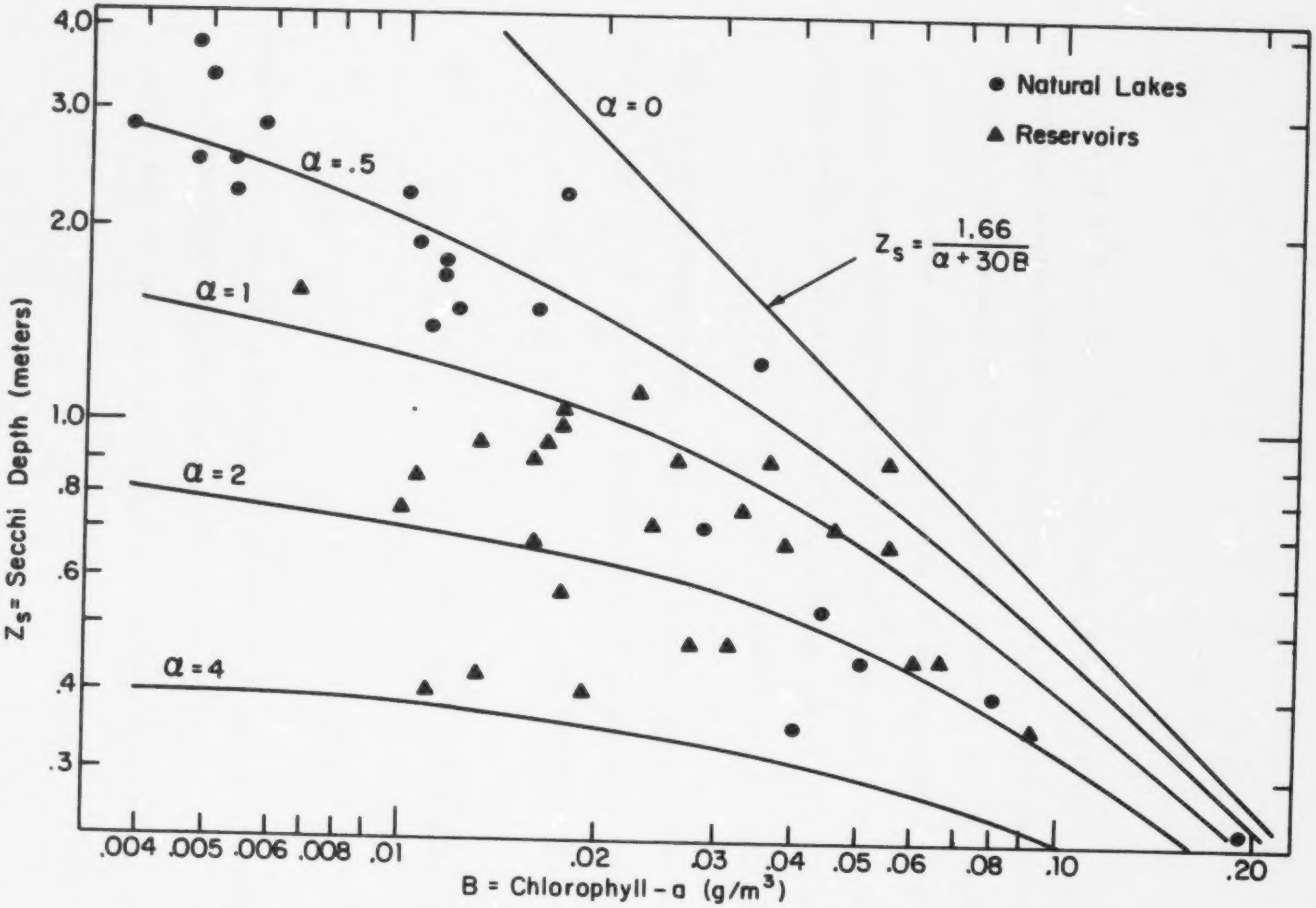

Figure C-6. Relationship between Secchi Depths and Chlorophyll-a Concentrations in Corn Belt Impoundments to natural lakes indicate the relative importance of non-algal suspended solids and color in controlling light penetration in the former systems.

To summarize, transparency is estimated according to the following equation:

$$\frac{k}{Z_S} = \varepsilon = \varepsilon_W + k_S S + k_C C + k_B B \qquad (38)$$

where,

$k = 1.66$

$\varepsilon_W = .04\ m^{-1}$

$k_S = .085\ m^2/g$ suspended solids

$k_C = .005\ m^{-1}/\mathrm{Pt\ Co\ Unit}$

$k_B = 30\ m^2/g$ Chlorophyll-a

The three independent variables in this equation (S, C, and B) are estimated for average summer conditions. Methods for estimating B are discussed in the next section.

Methods for estimating annual average S and C values have been discussed previously (Equations 3 and 33). Summer concentrations of suspended solids and color would tend to be considerably lower than annual average values, due to lower input rates and longer hydraulic residence times in impoundments during the summer months. Based upon analysis of data from Mississinewa Reservoir, Indiana (U.S. Army Corps of Engineers, 1977), summer average color and non-algal suspended solids concentrations are assumed to be one third of the respective annual, flow-weighted-average outflow concentrations:

$$S = C_{os}/F_{cs} \tag{39}$$

$$C = C_{oc}/F_{cs} \tag{40}$$

where,

$F_{cs} \simeq 3.0$

A factor of two might be explained rationally by the fact that mean summer flows are about one-half the annual average value in this region. This would approximately double hydraulic residence times during the summer (unless impoundment is used for flood control) and thus provide twice as much time for sedimentation and decay process. The additional reduction might be attributed to lower inflow concentrations during the summer months. Additional data and/or analyses are required to test and improve upon these assumptions.

Chlorophyll-a

Chlorophyll-a is a measure of phytoplankton densities in an impoundment. Along with hypolimnetic dissolved oxygen, transparency, and nutrient concentrations, summer chlorophyll-a is often used as an indicator of trophic state. In the interest of aesthetics, maintaining aerobic conditions in the bottom waters of impoundments and ecosystem "health," as indicated by the species present and their diversity, high chlorophyll concentrations are considered deterrents to water quality. In the interest of fish production, however, chlorophyll might be considered beneficial in certain concentration ranges.

The method developed below for predicting chlorophyll levels in corn belt impoundments is based largely upon theoretical considerations and is empirically calibrated and tested using data supplied by the NES. A basic assumption is that the growth of algal populations in these impoundments may be limited by light, phosphorus, and/or nitrogen supplies. The model is shown to have reasonable predictive capability, despite the fact that other types of growth limitation (in particular, carbon) have been ignored. Future improvements might be achieved by considering the effects of such additional factors. The model is developed below by (1) considering the limiting effects of each factor separately; (2) subsequently combining these effects; (3) calibrating empirically; and (4) presenting some evidence of verification. A preliminary error analysis and an interpretation of the results are also presented.

Light is a potentially important limiting factor, particularly in the turbid and colored waters characteristic of impoundments in the Corn belt. The effects of light limitation on algal production are represented below using a model originally developed by Lorenzen and Mitchell (1973) and later modified by Sykes (1975) and Walker (1977). The following simplified differential equation represents the growth of algae in the mixed surface layer of an impoundment (Lorenzen and

Mitchell, 1973).

$$\frac{dB}{dt} = (\mu - \delta)B \tag{41}$$

where,

B = biomass concentration (g Chl-a/m^3)

μ = growth rate ($days^{-1}$)

δ = decay rate ($days^{-1}$)

t = time (days)

The growth and decay rate parameters are evaluated at typical, summer, epilimnetic temperatures. The decay rate is assumed to represent the total effect of a number of processes, including respiration, settling, predation and flushing. Sykes (1975) suggested that Steele's (1962) formulation be used to represent the effect of light intensity on growth rate:

$$\frac{\mu}{\mu^{max}} = \frac{I_{z,t}}{I_s} \exp\left(1 - \frac{I_{z,t}}{I_s}\right) \tag{42}$$

where

$I_{z,t}$ = visible light intensity at depth Z and time of day t (cal/cm^2-hr)

I_s = saturation light intensity for algal specie (cal/cm^2-hr)

μ^{max} = growth rate at optimal light intensity ($days^{-1}$)

Variation of light intensity with depth is represented by Beer's Law:

$$I_{z,t} = I_{o,t} \exp^{(-\varepsilon Z)} \qquad (43)$$

where,

$I_{o,t}$ = surface light intensity at time of day t (cal/cm^2-hr)

ε = extinction coefficient (m^{-1})

As noted previously, the extinction coefficient is a linear function of algal density:

$$\varepsilon = \alpha + k_B B \qquad (44)$$

Variation of surface light intensity with time-of-day is represented by a cosine curve (Vollenweider 1966):

$$I_{o,t} = .5\, I_{o,m} \left(1 + \text{Cos}\, \frac{2\pi t}{\lambda}\right), \; -\frac{\lambda}{2} < t < \frac{\lambda}{2} \qquad (45)$$

$$= 0 \qquad , \text{otherwise}$$

where,

$I_{o,m}$ = surface light intensity at noon (cal/cm^2-hr)

λ = day length (hours)

t = time from noon (hours)

By integrating Equation 45 over one daily cycle, it can be shown that:

$$I_{o,m} = \frac{2\,\bar{I}_o}{\lambda} \qquad (46)$$

where,

$\bar{I}_o$ = total daily visible radiation (cal/cm^2 - day)

With other nutrients present in excess, the steady-state, light-limited algal density can be estimated by setting Equation 41 equal to zero, combining with Equations 42 - 46, integrating over mixed depth Z_e and over one, 24-hour cycle, and solving for B:

$$B_L = \frac{\mu^{max}}{\delta\,k_B}\frac{F}{Z_e} - \frac{\alpha}{k_B} \qquad (47)$$

$$F = \frac{e}{24}\int_0^{24}\left[\exp\left(-\frac{I_{o,t}}{I_s}\exp\left(-\varepsilon Z_e\right)\right) - \exp\left(-\frac{I_{o,t}}{I_s}\right)\right]dt \qquad (48)$$

where,

B_L = light-limited biomass (g Chl-a/m^3)

F = Surface light depth-integral (dimensionless)

Z_e = Epilimnion depth (m)

For a totally absorbing surface layer ($\varepsilon Z_e \gtrsim 5$),

the first term inside the integral of Equation 48 is essentially equal to one, and the integral can be evaluated numerically for the following typical parameter values:

$\bar{I}_o = 240$ cal/cm^2-day (McGauhey, 1968)

$\lambda = 13.5$ hours/day

$I_s = 2$ cal/cm^2-hr (Parsons and Takahachi, 1973)

I_o and λ values have been selected for an average summer day at 40^o latitude, assuming 75 percent of possible sunshine. The I_s value is at the lower end of the range of experimentally determined values and is thus appropriate for the shade-adapted algae which would be present under light-limited conditions. Accordingly, the F integral has been evaluated numerically to give:

$$F = .862\ e\ \frac{\lambda}{24} = 1.32 \tag{49}$$

The value of this integral is rather insensitive to the assumed values of $\bar{I}_o$ and I_s.

Another factor which needs to be evaluated in Equation 47 is μ^{max}/δ. Under light-limited conditions, the decay term, δ, would be governed by algal respiration, which is generally on the order of 10 percent of the maximum photosynthetic rate (Parsons and Takahachi, 1973). Accordingly, μ^{max}/δ is assumed to be 10. The incremental light extinction coefficient due to algae, k_B, has been estimated previously at 30

m^2/g Chl-a. Substituting the above parameter estimates into Equation 47 gives the following result:

$$B_L = \frac{K_L}{Z_e} - \frac{\alpha}{30} \tag{50}$$

$$K_L = \frac{\mu^{max} F}{\delta \; k_B} = .440 \tag{51}$$

B_L represents the maximum steady-state biomass which could exist in a horizontally-mixed impoundment when all nutrients except light are available at levels optimal for algal growth.

The average epilimnion depth, Z_e, is defined as the volume above the thermocline divided by total surface area. Assuming an inverted conical geometry for the impoundment bottom, Z_e is estimated as follows:

$$Z_e = \frac{V_e}{A_I} = Z \left(1 - \left(\frac{Z_{max} - Z_{th}}{Z_{max}}\right)^3\right) \tag{52}$$

$$Z = \frac{V}{A_I} \tag{53}$$

where,

V_e = epilimnion volume (m^3)

V = total volume (m^3)

A_I = surface area (m^2)

Z_{max} = maximum depth (m)

Z_{th} = thermocline depth (m)

Z = mean depth (m)

Snodgrass (1974) analyzed data from a number of northern lakes and derived the following empirical relationship:

$$Z_e = 1.6\ Z^{.57} \tag{54}$$

Using Z, Z_{max}, and Z_{th} values derived from July temperature profiles measured by ISBH (1976) in eight Indiana impoundments, Z_e values have been calculated according to Equation 52 and compared with the predictions of Equation 54. Agreement is reasonable, except for $Z < 3$ meters, in which Equation 54 gives Z_e values greater than Z. Accordingly, the following empirical method is used to estimate Z_e:

$$\begin{aligned} Z_e &= Z, \quad Z \leq 3\text{m} \\ Z_e &= 1.6\ Z^{.57}, \quad Z > 3\text{m} \end{aligned} \tag{55}$$

This method is appropriate for early summer conditions and may be less valid in reservoirs with unusual hydrodynamic characteristics.

Estimates of α, the residual, or non-algal component of the extinction coefficient can be derived from simultaneous Secchi depth and chlorophyll concentration measurements according to the following version of Equation 36.

$$\alpha = \frac{1.66}{Z_s} - 30\ B \tag{56}$$

When non-algal suspended solids and color measurements or estimates are available, α, can be estimated independently of B according to the following version of Equation 38.

$$\alpha = .04 + .085\ S + .005\ C \qquad (57)$$

In the calibration work discussed subsequently, Equation 56 is employed to derive α estimates from Z_s and B measurements in the NES impoundments. When the model is used in a predictive mode, Equation 57 is employed to permit estimation of α and B_L as a function of estimated suspended solids and color concentrations.

Equation 50 indicates that α values greater than $13.2/Z_e$ will prevent algal growth due to severe light limitation. Examination of data from the NES has revealed one impoundment, Lake Springfield, with a relatively low computed B_L value of .007 g Chl^{-a}/m^3. The observed mean chlorophyll-a concentration in this reservoir was .013 g Chl-a/m^3, almost twice the computed, maximum light-limited value. Similarly, Lake Lou Yaeger (in the verification data set) has a computed B_L value of -.060 g Chl-a/m^3 and an observed concentration of .011 g Chl-a/m^3. While errors in the data could be responsible for this, it is probable that Equation 50 is not valid as B_L approaches zero. Light limitation could not result in a complete absence of phytoplankton. Due to incomplete horizontal mixing, shallow bays and littoral areas could support algal growth in a turbid impoundment, despite the fact that average conditions in the epilimnion might not. In calibrating and applying the model, B_L is allowed to assume a minimum value of .020 g Chl-a/m^3.

This assumption influences the computed B_L values of only two out of the fifty impoundments used to calibrate the model.

The effects of phosphorus limitation upon algal production are estimated based upon kinetic and stoichiometric considerations. Employing Monod kinetics, the equation for algal growth as a function of available phosphorus concentration under optimal light and other nutritional conditions is given by:

$$\frac{dB}{dt} = (\mu^{max} \frac{\lambda}{24} \frac{P_a}{P_a+K_p} - \delta) B \tag{58}$$

where,

P_a = available phosphorus concentration (g P/m^3)

K_p = half-saturation constant for phosphorus uptake (g P/m^3)

This equation is analogous to Equation 41 for light limitation and assumes that light is available at optimal levels for algal growth during the day. At the maximum, phosphorus-limited biomass level, the available phosphorus concentration can be found by setting Equation 58 equal to zero and solving for P_a:

$$P_a = K_p \left(\frac{1}{\frac{\lambda}{24} \frac{\mu^{max}}{\delta} - 1} \right) \tag{59}$$

Under these conditions it is assumed that the rest of the phosphorus has been taken up by the algae:

$$B_p = \frac{p_t - p_a}{y_p} \tag{60}$$

where,

B_p = maximum, phosphorus-limited biomass (gChla/m^3)

y_p = algal p requirement (gP/m^3)

p_t = total phosphorus concentration (gP/m^3)

The following parameter values are assumed:

K_p = .01 g P/m^3 (DiToro et al., 1975)

$\mu^{max}/\delta = 10$ (Parsons and Takahachi, 1973)

y_p = 1 gP/gChl-a (DiToro, et al., 1975)

λ = 13.5 hours/day

Accordingly, Equation 60 can be evaluated as:

$$B_p = p_t - .0022 \tag{61}$$

Assuming that the median, summer total P concentrations reported by the NES are representative at p_t values, B_p can be linked to average outflow P concentrations using Equations 19 and 20 for natural lakes and reservoirs, respectively. These, in turn, can be related to average inflow P concentrations and retention coefficients using Equations 17 and 18.

The effects of nitrogen limitation on algal production are represented in an analogous fashion:

$$n_a = K_n \frac{1}{\frac{\lambda}{24}\frac{\mu_{max}}{\delta} - 1} \qquad (62)$$

$$B_N = (n_t - n_a)/Y_N \qquad (63)$$

where,

n_a = available nitrogen concentrations (g N/m^3)

K_n = half-saturation consistent for nitrogen uptake (gN/m^3)

n_t = total nitrogen concentrations (gN/m^3)

Y_N = algal n requirements (gN/gChl-a)

B_N = maximum, nitrogen-limited biomass (g Chl-a/m^3)

The following parameter values are assumed:

K_n = .01 g/m^3

y_n = 7 gN/gChl-a (Parsons and Takahachi, 1973)

Accordingly, B_N is given by:

$$B_N = (n_t - .0022)/7 \tag{64}$$

This equation ignores the possible effects of nitrogen fixation by blue-green algae and is therefore not valid under conditions in which that phenomenon is important. It is assumed that n_t is related to average outflow nitrogen concentration in a manner similar to that observed in the case of phosphorus, although no data are available from the NES to verify this.

Given the above expressions for the maximum light-, phosphorus,- and nitrogen-limited biomass levels, a means of estimating the effects of simultaneous limitation by more than one factor is required. A model of the following general form is proposed for that purpose:

$$\left(\frac{1}{B}\right)^m = \left[f_o + \left(\frac{f_L}{B_L}\right)^m + \left(\frac{f_P}{B_P}\right)^m + \left(\frac{f_N}{B_N}\right)^m\right] \tag{65}$$

where,

B = observed, mean summer chlorophyll-a concentration (g/m^3)

m, f_O, f_L, f_P, f_N = empirical parameters.

One characteristic of the formulation is that, for $m > 0$, a relatively low value of B_L/f_L would cause the corresponding term to dominate the right side of the equation. In that case, light would be controlling the biomass level. Similarly, phosphorus or nitrogen could be controlling. The parameter m determines the extent to which more than one factor can be simultaneously important in determining the biomass level. As m increases, the relative magnitudes of the various limiting factor terms become increasingly different, permitting only one term to dominate at a time. As m approaches zero, the factor terms become increasingly similar and the model approaches a multiplicative one. The value of $(f_L/B_L)^m$, for example, could be viewed as a measure of the resistance to algal growth attributed to light limitation. In that sense, with $f_0 = 0$, Equation 65 is equivalent to the formula for the total resistance of an electrical circuit consisting of three resistors connected in series. The empirical parameters have been included to permit calibration of the model and testing of the significance of each term.

Calibration of Equation 65 has been achieved by employing the BMDP Nonlinear Regression Analysis Program, BMDP3 (Dixon, 1975). Coefficients have been selected to minimize the sums of squares of residuals, expressed as the differences between the observed and estimated, transformed chlorophyll-a concentrations. The following transformation has been found to give normally distributed, homoscedastic residuals:

$$B_t = -1./\sqrt{B} \tag{66}$$

where,

B_t = transformed chlorophyll-a concentration. $(\text{g Chl-a/m}^3)^{-\frac{1}{2}}$

Optimal values of f_o, f_L, f_P, and f_N have been estimated for various assumed values of m, ranging from .125 to 2.5. In addition, K_L, a parameter in the light limited biomass expression (Equation 51), has been optimized. Since the K_L value given in Equation 51 was derived from a variety of theoretical assumptions and "literature" values of the parameters μ^{max}/δ and I_s, both of which are subject to error, optimization of this parameter is considered both desirable and permissable without sacrificing the theoretical basis of the model.

Initial calibration runs using data from 50 impoundments have indicated that optimal values f_o and f_N are not significantly different from zero for any of the assumed values of m (.125, .25, .5, 1.0, 1.5, and 2.0). With these parameters set equal to zero, the value of m which gives the smallest mean squared residual is 1.0. Optimal coefficients for this case are as follows:

$f_P = 1.866 \pm .149$

$f_L = 1.363 \pm .333$

$K_L = .440 \pm .052$

With these coefficient values, Equation 65 explains 82.4 percent of the variance of B_t, with a standard error of 1.378. Observations are plotted against model predictions in Figure C-7.

Three strategies have been employed to test the model: (1) analysis of residuals; (2) tests for parameter stability; and (3) tests on an independent data set. Results of these tests are discussed below.

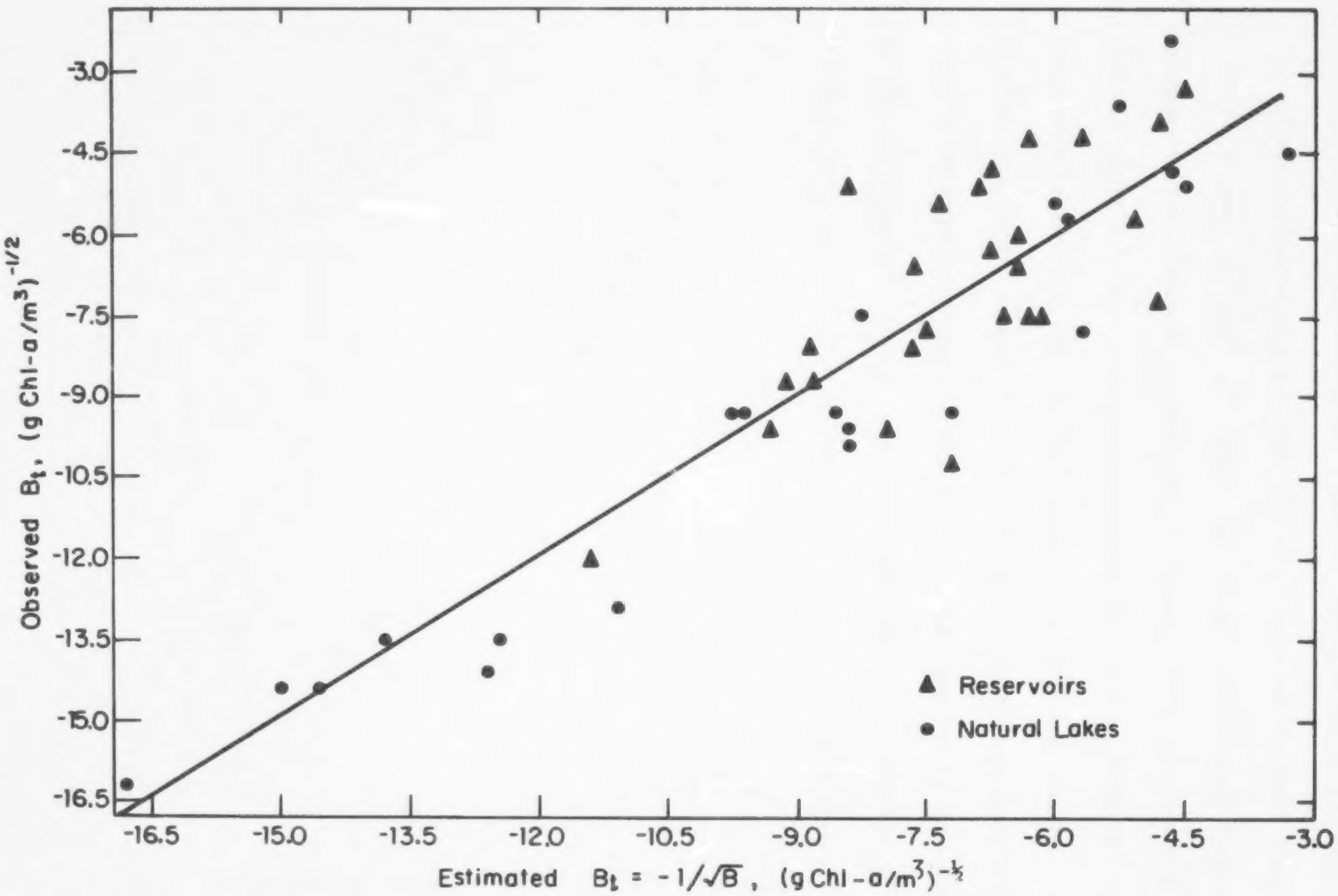

Figure C-7. Relationship between Observed and Estimated Transformed Chlorophyll-a Concentrations in Corn Belt Impoundments

The residuals of the model have been tested for normality and plotted against a variety of regional, morphometric, hydrologic, and nutritional factors derived from the data in the attached tables While formal statistical tests for normality have not been applied, a normal probability plot appears to be linear (Figure C-8). Examination of other residuals plots has revealed a slight negative bias (averaging about -.7 or one half of the standard error) in the ten impoundments with hydraulic residence times less than .1 years. This may indicate that flushing is an important removal mechanism (compared with respiration, for example) in these impoundments. Future versions of the model

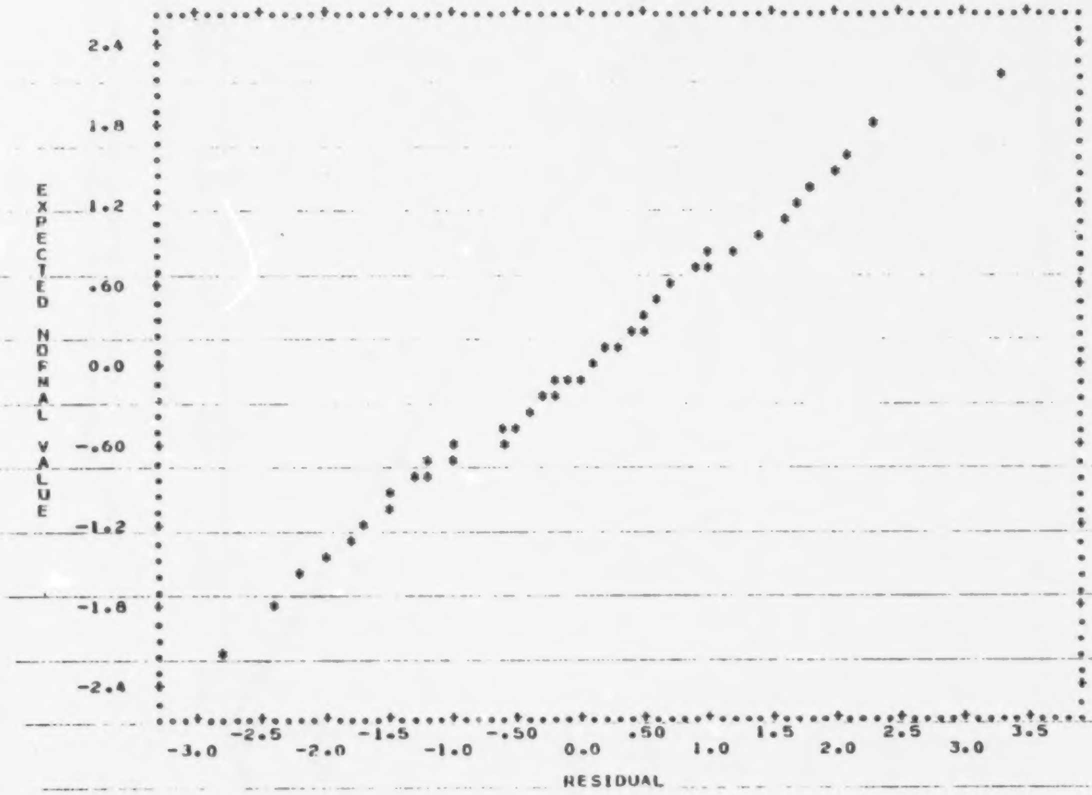

Figure C-8. Normal Probability Plot of Residuals from Chlorophyll-a Model could account for this by calculating δ (Equations 41 and 58) as a partial function of residence time. A plot of residuals against longitude indicates a slight positive bias (again averaging about one half of the standard error) in the seven impoundments east of the 83° meridian. The source of this bias is unknown. Aside from the apparent biases discussed above (neither of which is statistically significant), no systematic deviations have been detected in residuals plots.

Tests of parameter stability have also been performed in order to develop some evidence of model verification. The data set has been divided into two groups (23 natural lakes and 27 reservoirs) and optimal f_P, f_L, and K_L values have been estimated for each group and for assumed m values of .5, 1.0, and 1.5. An F test based upon residual sums of squares (Dixon, 1975) has been used to test for significant parameter variations across groups for each assumed value of m. Computed F statistics for assumed m values of .5, 1.0, and 1.5 are 1.89, .93, and 1.01, respectively, with 3 and 44 degrees of freedom. At the 90% confidence level, an F ratio of 2.43 or higher would indicate significant parameter variations across groups. While this test is only approximate in the case of a nonlinear model, the apparent stability in the parameters is evidence for verification of the model and further justification for the selection of an m value of 1.0, which resulted in the lowest F ratio.

The model has also been tested using data from 20 other NES impoundments in the Midwest, including seven from Illinois, one from Indiana, three from Ohio, and nine from Iowa (listed in Attachment).

Some of the data are from impoundments which were omitted from the calibration data set for one or more of the reasons listed previously (see Data Base). The computed standard error of B_t estimates for these 20 lakes is 2.58, considerably larger than the standard error in the data base used for calibration, 1.38. Examination of the residuals reveals a strong negative bias (about three standard errors) in the residuals from the three impoundments with overflow rates greater than 150 m/year or residence times less than three days (Charleston, Beach City, and O'Shanghnessy). This suggests that flushing may be an important algal removal mechanism in these impoundments, as noted in the residuals plots discussed above. Another impoundment with a highly negative residual, Lake Weematuk, was sampled only twice by the NES during the summer of 1974. The chlorophyll estimate for this impoundment is therefore less reliable than for the others. Finally, outflow phosphorus concentrations in Lake Aquabi were sampled only five times by the NES, as compared with 12 or 13 samplings in the other NES impoundments. If, for the above reasons, these five impoundments are rejected from the data set, the standard error of the chlorophyll model reduces to 1.38, in agreement with that observed in the data base used for calibrating the model.

One potential problem with the parameter estimation procedure is that estimates of the independent variable α, obtained from the NES data according to Equation 56 are dependent upon observed Secchi disc and chlorophyll values. Thus, in the above estimation procedure, B appears implicitly on both sides of equation. It would have been preferable to have derived α estimates from independent suspended solids and color measurements, had these data been available. This procedure used for estimating α may have inflated the apparent R^2 of the model and the significance of the B_L term. The correlation coefficient between α and B is .10, however, indicating that variations in α are governed chiefly by variations in Secchi depth and are nearly independent of B values. This suggests that α is chiefly a measure of non-algal turbidity and color and is not very sensitive to errors in chlorophyll estimates. Variations in B_L, according to Equation 50, are also governed mostly by the changes in Z_e, as opposed to changes in α. Thus, the problems arising from use of this procedure may not be important, although the model should be verified using α estimates derived independently, should such data be available in the future.

Using expected value theory, it can be shown that the coefficient of variation of a chlorophyll-a estimate derived from this model is given approximately by:

$$CV_B = 2\sqrt{B}\ \sigma_e = 2.76\ \sqrt{B} \qquad (67)$$

where,

B = estimated chlorophyll concentration (g/m^3)

CV_B = coefficient of variation of B

σ_e = standard error of model = 1.378

This equation does not consider the effects of parameter errors, which would be important only at extreme values of the independent variables.

At the average B_t value for the data set, the computed coefficient of variation of B is .348. This corresponds roughly to a 95 percent confidence range of ± 70 percent in the B estimate, a fairly wide error margin.

A preliminary error analysis has been performed in order to partition the observed error into model and measurement error components. An important measurement error component is that associated with estimating mean summer chlorophyll-a concentrations from grab samples taken by the NES generally on three dates for each impoundment. This error has been quantified by compiling and analyzing the spatially-averaged chlorophyll data for each sampling data and impoundment. The computed average coefficient of variation of the mean chlorophyll estimates for fifty impoundments is .30. This can be compared with the model residuals, which indicate an average coefficient of variation of .35, as calculated above. Thus, an appreciable portion of the observed error can be attributed to sampling errors in the mean chlorophyll values due to temporal averaging. This does not include errors due to spatial averaging. Other types of measurement errors are associated with the independent variables in the model, including phosphorus concentrations, Secchi depths and epilimnion depths. Any remaining error can be attributed to the effects of factors not considered in the model. Based upon the above analysis, that component is probably small compared with the measurement error component. Thus, the actual model error is predicting chlorophyll values is probably considerably less than that computed according to Equation 67.

The insignificance of the nitrogen term in Equation 65 is not surprising, in view of the excess nitrogen supplies in these impoundments, as discussed previously (see Nitrogen Trapping and Concentration). The average value of B_N for the data set is .287 g Chl-a/m^3, compared with average B_L and B_P values of .094 and .077 g Chl-a/m^3, respectively. Thus, nitrogen supplies for algal growth are about three and four times in excess of light and phosphorus supplies, respectively. It is possible, however, that inclusion of the nitrogen term in Equation 65 could be justified, given data from impoundments with lower nitrogen concentrations. In applying the model to assess soil management practices, the nitrogen term is tentatively included with an assumed value of f_N equal to f_P (1.866).

The empirically optimal value of K_L is .440 ± .052, identical to the theoretically proposed value. This is surprising, in view of the assumptions and literature parameter values which went into the theoretical estimate. While other "theoretical" values of K_L are perhaps equally justifiable, the agreement between the empirical and a-priori values of this parameter lends some strength to the validity of the model.

One theoretical interpretation of these results is that f_L/B_L and f_P/B_P are measures of the resistance to algal growth due to light and phosphorus limitation, respectively. Figure C-9 plots these resistance values, using different symbols for reservoirs and natural lakes. The dashed lines in Fig. C-9 represent lines of equal biomass potential, computed as the inverse of the sum of the two resistance terms, accord-

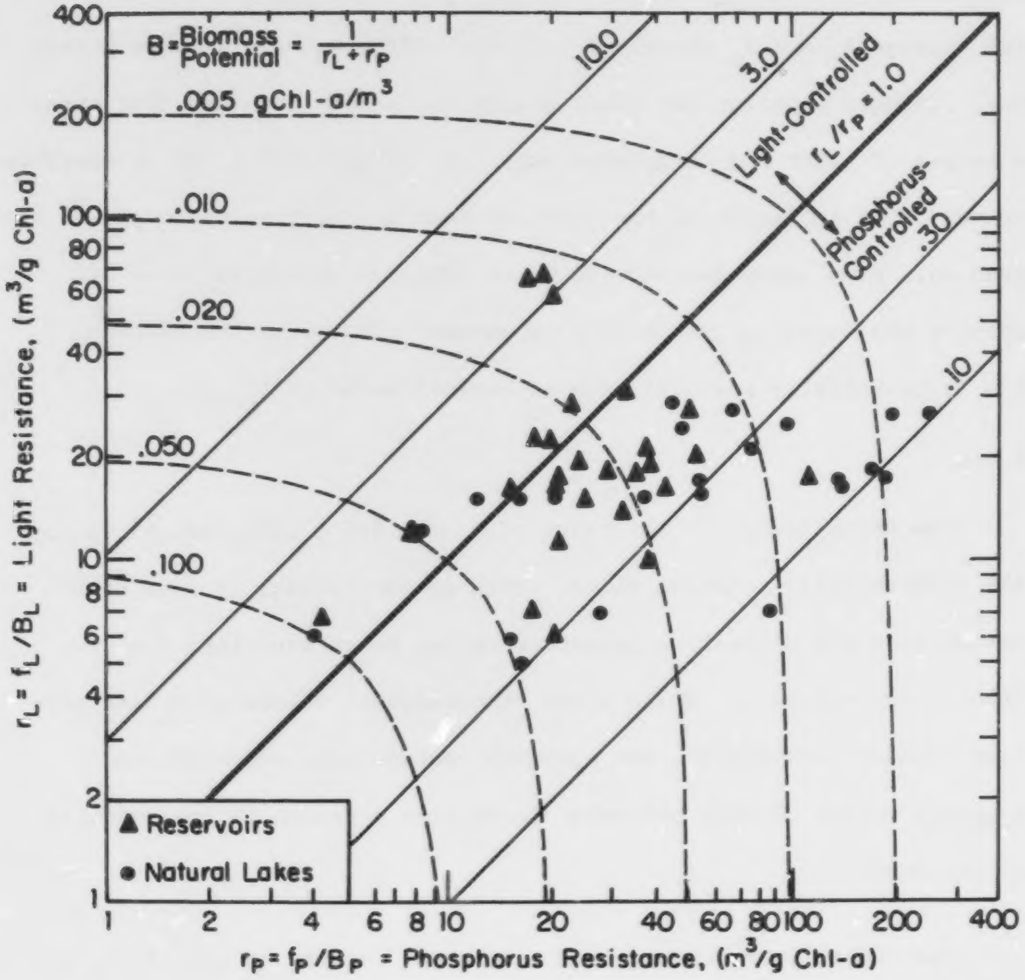

Figure C-9. Relationship between Light Resitance and Phosphorus Resistance to Algal Growth in Corn Belt Impoundments ing to Equation 65. The potential ranges from about .003 g Chla/m^3 in the marl lakes of Northern Indiana to about .100 g Chl-a/m^3 in Buckeye Lake, Ohio. The solid, diagonal lines represent different ratios of light resistance to phosphorus resistance. Most of the impoundments fall below the main diagonal, where phosphorus is the dominant controlling factor. Light appears to be more important in reservoirs than in natural lakes, as indicated by the relative positions of these two groups on the plot. Higher turbidity, color, and phosphorus concentrations are typical of reservoirs in this data set. All of these characteristics could be related to the lower geometric mean hydraulic residence time of these reservoirs (.24 years), as compared with natural lakes (.46 years). Due to increased trapping/decay of sediment, color, and phosphorus, impoundments with higher residence times would be expected to be increasingly phosphorus-limited.

The following equations summarize the predictive methodology developed for mean summer, epilmnetic chlorophyll-a concentrations:

$$B_P = P_t - .0022 \qquad (68)$$

$$B_N = (n_t - .0022)/7 \qquad (69)$$

$$B_L = \frac{.440}{Z_e} - \frac{\alpha}{30} \qquad (70)$$

$$\frac{1}{B} = \frac{1.866}{B_P} + \frac{1.866}{B_N} + \frac{1.363}{B_L} \qquad (71)$$

In applying this model to evaluate the effects of soil management practices on water quality, the following relationships are also employed to estimate the independent variables:

$$p_t = .778\ C_{op} \qquad (72)$$

$$n_t = .778\ C_{on} \qquad (73)$$

$$\begin{aligned} Z_e &= 1.6\ Z^{.57}, & Z > 3\text{m} \qquad (74)\\ &= Z, & Z \leq 3\text{m} \end{aligned}$$

$$\alpha = .04 + .085S + .005\ C \qquad (75)$$

The numerical constant in Equations 72 and 73 represents the geometric mean ratio of median, summer total phosphorus to mean annual outflow phosphorus in the fifty impoundments used for model calibration. It should be noted again that inclusion of a nitrogen term has not been empirically verified, possibly because of the excessive nitrogen supplies in the impoundments used for calibration. Model predictions under nitrogen-limited conditions are therefore considerably less reliable than those made under phosphorus- and/or light-limited conditions.

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ATTACHMENT TO APPENDIX C

Tables of Data Used in Calibrating and Testing Impoundment Models

Key to Symbols Used in Data Tables

ID= U.S.E.P.A. National Eutrophication Survey Working Paper Number

NAME= Impoundment Name

STATE= Location

TROPHIC= Trophic State (EUTR= Eutrophic, MESO= Mesotrophic, OLIG= Oligotrophic)

TYPE= Impoundment Type (RES= Reservoir, NAT= Natural Lake)

LATI= Degrees, North Latitude

LONG= Degrees, West Longitude

AS= Surface Area (km^2)

AD= Drainage Area, excluding impoundment surface, (km^2)

Z= Mean Depth (m)

ZMAX= Maximum Depth (m)

T= Mean Hydraulic Residence Time (years)

QS= Surface Overflow Rate (m/yr)

LP= Total Phosphorus Loading (g/m^2-yr)

RP= Total Phosphorus Retention Coefficient (dimensionless)

CIP= Average Inflow Phosphorus Concentration (g/m^3)

COP= Average Outflow Phosphorus Concentration (g/m^3)

UP= Phosphorus Settling Velocity (m/yr)

LN= Total Nitrogen Loading (g/m^2-yr)

RN= Total Nitrogen Retention Coefficient (dimensionless)

CIN= Average Inflow Nitrogen Concentration (g/m^3)

CON= Average Outflow Nitrogen Concentration (g/m^3)

UN= Nitrogen Settling Velocity (m/yr)

CHLA= Mean Summer Chlorophyll-a Concentration (mg/m^3)

ALPHA= Non-algal Portion of Visible Light Extinction Coefficient=
$\frac{1.66}{\mathrm{ZSEC}} - .03\ \mathrm{CHLA}\ (\mathrm{m}^{-1})$

ZSEC= Mean Summer Secchi Depth (m)

DOMN= Minimum Hypolimnetic Dissolved Oxygen Concentration (g/m^3)

TPM= Median Summer Total Phosphorus (g/m^3)

OPM= Median Summer Ortho- Phosphorus (g/m^3)

INM= Median Summer Inorganic Nitrogen (g/m^3)

ST= Sedimentation Rate (kg/m^2-yr)

LS= Apparent Sediment Loading (kg/m^2-yr)

LP'= "Corrected" Total Phosphorus Loading (g/m^2-yr)

RP'= "Corrected" Total Phosphorus Retention Coefficient (dimensionless)

UP'= "Corrected" Total Phosphorus Settling Velocity (m/yr)

Table C-A. Data Used for Model Calibration

ID	NAME	STATE	TROPHIC	TYPE	LATI	LONG	AS	AD	Z	ZMAX	T	Q5
296	BLOOMINGTON	ILL	EUTR	RES	40.650	88.920	1.970	178.0	5.000	10.700	0.290	17.241
297	CARLYLE	ILL	EUTR	RES	38.670	89.250	105.200	6937.0	2.700	11.000	0.180	15.000
301	CRAB ORCHARD	ILL	EUTR	RES	37.720	89.080	28.190	492.4	3.000	6.100	0.790	3.797
302	DECATUR	ILL	EUTR	NAT	39.800	88.080	11.350	2418.0	1.400	4.600	0.030	46.667
309	LONG	ILL	EUTR	NAT	42.380	88.130	1.030	98.7	1.600	4.900	0.088	18.182
312	RACOON	ILL	EUTR	RES	38.550	89.080	3.930	122.0	1.200	3.700	0.200	6.000
313	REND	ILL	EUTR	RES	38.080	89.970	76.490	1224.0	4.700	6.600	1.250	3.760
315	SHELBYVILLE	ILL	EUTR	RES	39.500	88.630	44.520	2685.0	5.000	15.500	0.360	13.889
317	SPRINGFIELD	ILL	EUTR	RES	39.720	89.600	17.130	664.1	4.000	6.100	0.480	8.333
318	STOREY	ILL	EUTR	RES	40.530	90.400	0.530	17.7	4.600	7.200	0.770	5.974
320	VERMILION	ILL	EUTR	RES	40.170	87.650	2.830	771.6	1.400	4.600	0.025	56.000
322	WONDER	ILL	EUTR	RES	42.380	88.350	2.950	249.0	2.500	6.200	0.150	16.667
323	BASS	IND	EUTR	NAT	41.220	86.580	5.690	7.7	1.800	9.800	3.200	0.563
324	CATARACT	IND	EUTR	RES	39.480	86.920	5.660	756.3	6.100	17.000	0.140	43.571
325	CROOKED	IND	MESO	NAT	41.670	85.050	3.250	27.6	6.100	23.500	2.600	2.346
326	DALLAS	IND	EUTR	NAT	41.550	85.420	1.140	102.0	10.800	29.300	0.410	26.341
327	GEIST	IND	EUTR	RES	39.920	85.950	7.290	552.0	3.600	6.700	0.160	22.500
328	HAMILTON	IND	EUTR	NAT	41.550	84.920	3.250	39.6	6.300	21.300	1.800	3.500
330	JAMES LAKE	IND	EUTR	NAT	41.320	85.730	1.140	144.8	8.200	19.200	0.220	37.273
331	L JAMES	IND	MESO	NAT	41.700	85.030	4.180	119.6	7.300	26.200	0.860	8.488
332	LONG	IND	EUTR	NAT	41.580	85.030	0.370	175.7	5.100	9.700	0.036	141.667
333	MARSH	IND	EUTR	NAT	41.720	84.980	0.230	38.4	6.100	11.600	0.120	50.833
334	MISSISSINEWA	IND	EUTR	RES	40.670	85.920	12.750	2078.0	7.200	34.700	0.140	51.429
335	MAXINKUCKEE	IND	MESO	NAT	41.200	86.400	7.540	28.0	7.300	26.800	6.700	1.090
336	MONROE	IND	EUTR	RES	39.080	86.420	43.500	1076.2	5.300	22.200	0.660	8.030
337	MORSE	IND	EUTR	RES	40.080	86.030	5.570	549.7	4.700	15.200	0.150	31.333
338	OLIN	IND	MESO	NAT	41.570	85.390	0.420	14.6	11.700	25.000	1.100	10.636
339	OLIVER	IND	MESO	NAT	41.580	85.400	1.500	27.2	12.200	27.700	2.300	5.304
340	PIGEON	IND	EUTR	NAT	41.640	84.950	0.250	82.7	4.600	11.600	0.047	97.872
342	TIPPECANOE	IND	MESO	NAT	41.330	85.770	3.110	289.6	11.300	37.500	0.410	27.561
344	WAWASEE	IND	MESO	NAT	41.400	85.700	12.380	81.8	6.700	23.500	3.500	1.914
345	WEBSTER	IND	EUTR	NAT	41.320	85.670	2.370	124.3	2.100	13.700	0.130	16.154
346	WESTLER	IND	EUTR	NAT	41.320	85.390	0.360	97.5	6.100	11.600	0.074	82.432
347	WHITEWATER	IND	EUTR	RES	39.610	84.970	0.810	49.0	4.600	14.900	0.260	17.692
348	WINONA	IND	EUTR	NAT	41.220	85.830	2.270	80.8	9.100	24.400	0.870	10.460
349	WITMER	IND	EUTR	NAT	41.530	85.400	0.830	92.7	10.400	16.500	0.320	32.500
393	ATWOOD	OHIO	EUTR	RES	40.540	81.250	6.230	174.8	4.700	8.200	0.490	9.592
395	BERLIN	OHIO	EUTR	RES	41.000	81.080	8.900	633.0	4.900	14.000	0.222	22.072
396	BUCKEYE	OHIO	EUTR	NAT	39.920	82.500	12.710	102.0	1.900	4.000	0.640	2.969
397	CHARLES MILL	OHIO	EUTR	RES	40.750	82.370	5.460	557.0	1.700	9.400	0.055	30.909
398	DEEPCREEK	OHIO	EUTR	RES	39.720	83.250	5.170	712.0	5.000	10.400	0.120	41.667
399	DELAWARE	OHIO	EUTR	RES	40.330	83.170	5.260	994.6	3.300	9.400	0.063	52.381
400	DILLON	OHIO	EUTR	RES	40.000	82.080	5.360	1916.0	3.000	7.600	0.025	120.000
401	GRANT	OHIO	EUTR	NAT	39.000	83.930	0.760	67.3	1.900	8.100	0.067	28.358
402	HOLIDAY	OHIO	EUTR	RES	41.100	82.730	0.190	34.8	3.900	4.900	0.280	13.929
403	HOOVER	OHIO	EUTR	RES	40.080	82.870	11.430	481.0	6.500	17.600	0.490	13.265
406	MOSQUITO CRE	OHIO	EUTR	RES	41.330	80.750	31.570	221.0	2.700	6.100	0.960	2.812
408	PLEASANT HIL	OHIO	EUTR	RES	40.630	82.330	3.440	507.0	4.800	11.000	0.096	50.000
409	ROCKFORK	OHIO	EUTR	RES	39.180	83.500	0.170	287.2	5.100	12.100	0.390	13.077
411	ST MARYS	OHIO	EUTR	NAT	40.530	84.500	44.520	246.0	3.000	7.500	1.600	1.875
	MEAN				40.558	85.566	11.423	588.5	5.088	13.982	0.726	26.918
	STD DEV				1.094	2.431	20.046	1108.7	2.823	8.510	1.179	30.237
	MINIMUM				37.720	80.750	0.190	7.7	1.200	3.700	0.025	0.563
	MAXIMUM				42.380	90.400	105.200	6937.0	12.200	37.500	6.700	141.667
	MEDIAN				40.710	85.410	4.675	176.8	4.750	11.300	0.285	18.410

Table C-A (cont'd). Data Used for Model Calibration

ID	NAME	LP	RP	CIP	COP	UP	LN	RN	CIN	CON	UN
296	BLOOMINGTON	2.170	0.310	0.126	0.087	7.746	174.100	-0.100	10.098	11.108	-1.567
297	CARLYLE	3.000	0.390	0.200	0.122	9.590	48.200	0.100	3.213	2.892	1.667
301	CRAB ORCHARD	2.820	0.780	0.743	0.163	13.464	13.000	0.550	3.423	1.540	4.641
302	DECATUR	9.150	0.260	0.196	0.145	16.396	239.600	-0.190	5.134	6.110	-7.451
309	LONG	23.660	0.620	1.301	0.494	29.665	114.800	0.550	6.314	2.841	22.222
312	RACOON	1.170	0.280	0.195	0.140	2.333	19.500	0.430	3.250	1.852	4.526
313	REND	0.970	0.500	0.258	0.129	3.760	9.900	0.420	2.633	1.527	2.723
315	SHELBYVILLE	4.120	0.660	0.297	0.101	26.961	85.900	0.220	6.185	4.824	3.917
317	SPRINGFIELD	1.700	0.250	0.204	0.153	2.778	63.900	0.340	7.668	5.061	4.293
318	STOREY	2.180	0.690	0.365	0.113	13.297	43.500	0.280	7.282	5.243	2.323
320	VERMILION	10.200	0.330	0.182	0.122	27.582	388.000	0.070	6.929	6.444	4.215
322	WONDER	12.390	0.560	0.743	0.327	21.212	82.900	0.410	4.974	2.935	11.582
323	BASS	0.090	0.440	0.160	0.090	0.442	3.300	0.420	5.867	3.403	0.407
324	CATARACT	5.650	0.430	0.130	0.074	32.870	183.100	0.260	4.202	3.110	15.309
325	CROOKED	0.240	0.790	0.102	0.021	8.826	6.500	0.540	2.770	1.274	2.754
326	DALLAS	1.530	0.070	0.058	0.054	1.983	62.900	0.330	2.388	1.600	12.974
327	GEIST	2.880	0.400	0.128	0.077	15.000	91.400	-0.020	4.062	4.143	-0.441
328	HAMILTON	0.320	0.470	0.091	0.048	3.104	12.000	0.530	3.429	1.611	3.947
330	JAMES LAKE	1.300	-0.030	0.035	0.036	-1.086	88.800	0.040	2.382	2.287	1.553
331	L JAMES	0.340	0.590	0.040	0.016	12.215	13.400	0.460	1.579	0.852	7.231
332	LONG	29.540	0.330	0.209	0.140	69.776	596.700	0.100	4.212	3.791	15.741
333	MARSH	6.090	0.060	0.120	0.113	3.245	83.700	-0.020	1.647	1.679	-0.997
334	MISSISSINEWA	12.590	0.490	0.245	0.125	49.412	256.300	0.270	4.984	3.638	19.022
335	MAXINKUCKEE	0.150	0.870	0.138	0.018	7.292	5.600	0.800	5.140	1.028	4.358
336	MONROE	0.280	0.430	0.035	0.020	6.058	9.000	0.010	1.121	1.110	0.081
337	MORSE	6.520	0.530	0.208	0.098	35.333	157.800	0.110	5.036	4.482	3.873
338	OLIN	0.810	0.790	0.076	0.016	40.013	34.600	0.380	3.253	2.017	6.519
339	OLIVER	0.160	0.560	0.030	0.013	6.751	15.700	0.440	2.960	1.658	4.168
340	PIGEON	8.320	0.200	0.085	0.068	24.468	423.900	0.130	4.331	3.768	14.625
342	TIPPECANOE	1.100	0.290	0.040	0.028	11.257	68.300	0.190	2.478	2.007	6.465
344	WAWASEE	0.110	0.640	0.057	0.021	3.403	8.700	0.620	4.545	1.727	3.123
345	WEBSTER	1.040	0.500	0.064	0.032	16.154	52.200	0.240	3.231	2.456	5.101
346	WESTLER	4.390	0.110	0.053	0.047	10.188	158.700	-0.170	1.925	2.252	-11.977
347	WHITEWATER	3.280	0.640	0.185	0.067	31.453	89.100	0.240	5.036	3.827	5.587
348	WINONA	0.800	0.480	0.076	0.040	9.655	39.800	0.230	3.805	2.930	3.124
349	WITMER	2.730	0.330	0.084	0.056	16.007	79.700	0.190	2.452	1.986	7.623
333	ATWOOD	1.670	0.650	0.174	0.061	17.813	21.800	0.270	2.273	1.659	3.548
395	BERLIN	5.870	0.760	0.266	0.064	69.895	59.700	0.260	2.705	2.002	7.755
396	BUCKEYE	0.510	0.100	0.172	0.155	0.330	8.800	0.230	2.964	2.282	0.887
397	CHARLES MILL	5.560	0.170	0.180	0.149	6.331	91.000	0.100	2.944	2.650	3.434
398	DEERCREEK	5.540	0.200	0.133	0.106	10.417	140.100	-0.060	3.362	3.564	-2.358
399	DELAWARE	12.490	0.420	0.238	0.138	37.931	224.200	0.110	4.280	3.809	6.474
400	DILLON	32.910	0.510	0.274	0.134	124.898	468.800	0.220	3.907	3.047	33.846
401	GRANT	8.510	0.150	0.300	0.255	5.004	56.900	-0.210	2.006	2.428	-4.922
402	HOLIDAY	8.410	0.800	0.604	0.121	55.714	68.800	0.540	4.939	2.272	16.351
403	HOOVER	1.740	0.650	0.131	0.046	24.636	32.800	0.100	2.473	2.225	1.474
406	MOSQUITO CRE	0.320	0.440	0.114	0.064	2.210	6.100	0.280	2.169	1.562	1.094
408	PLEASANT HIL	3.510	0.210	0.070	0.055	13.291	88.800	0.130	1.776	1.545	7.471
409	ROCKFORK	2.050	0.710	0.157	0.045	32.016	32.300	0.280	2.470	1.778	5.085
411	ST MARYS	0.490	0.310	0.261	0.180	0.842	9.100	0.420	4.853	2.815	1.358
	MEAN	5.067	0.442	0.207	0.100	19.799	102.673	0.241	3.861	2.893	5.295
	STD DEV	7.046	0.225	0.221	0.085	22.880	128.192	0.220	1.790	1.755	7.518
	MINIMUM	0.090	-0.030	0.030	0.013	-1.086	3.300	-0.210	1.121	0.852	-11.977
	MAXIMUM	32.910	0.870	1.301	0.494	124.898	598.700	0.800	10.098	11.108	33.846
	MEDIAN	2.455	0.440	0.158	0.082	12.753	63.400	0.240	3.393	2.357	4.057

Table C-A (cont'd). Data Used for Model Calibration

ID	NAME	CHLA	ZSFC	ALPH	DOWN	TPM	OPM	INM
296	BLOOMINGTON	26.200	0.897	1.065	0.200	0.050	0.020	5.730
297	CARLYLE	17.400	0.564	2.422	4.000	0.084	0.032	1.270
301	CRAB ORCHARD	59.900	0.452	1.875	2.000	0.082	0.013	0.200
302	DECATUR	43.000	0.518	1.914	0.500	0.129	0.002	3.750
309	LONG	49.300	0.439	2.299	6.200	0.704	0.398	1.190
312	RACOON	19.200	0.399	3.587	1.200	0.106	0.020	0.310
313	REND	23.500	0.724	1.588	2.300	0.071	0.012	0.210
315	SHELBYVILLE	17.200	0.983	1.173	1.000	0.062	0.019	3.290
317	SPRINGFIELD	13.000	0.422	3.547	4.200	0.108	0.059	3.270
318	STOREY	17.300	1.034	1.087	0.200	0.072	0.021	2.510
320	VERMILION	31.200	0.470	2.597	0.600	0.109	0.050	4.700
322	WONDER	90.500	0.356	1.953	7.200	0.426	0.132	0.890
323	BASS	29.400	0.726	1.403	8.000	0.040	0.012	0.250
324	CATARACT	10.700	0.846	1.642	0.0	0.058	0.013	1.660
325	CROOKED	5.580	2.283	0.560	0.0	0.019	0.005	0.120
326	DALLAS	10.100	2.202	0.451	0.0	0.029	0.014	0.830
327	GEIST	46.000	0.699	0.997	3.400	0.074	0.009	1.080
328	HAMILTON	17.500	2.205	0.228	0.0	0.033	0.018	0.720
330	JAMES LAKE	11.500	1.676	0.645	0.0	0.024	0.008	1.030
331	L JAMES	4.860	3.749	0.297	0.0	0.016	0.005	0.190
332	LONG	16.100	1.455	0.658	0.0	0.204	0.150	1.920
333	MARSH	34.500	1.237	0.307	0.0	0.093	0.055	0.270
334	MISSISSINEWA	15.800	0.676	1.983	0.0	0.107	0.029	2.400
335	MAXINKUCKEE	5.480	2.530	0.492	0.0	0.020	0.003	0.220
336	MONROE	6.950	1.554	0.859	0.0	0.025	0.007	0.330
337	MORSE	56.200	0.681	0.753	0.0	0.084	0.009	3.330
338	OLIN	4.870	2.456	0.530	0.100	0.012	0.003	1.460
339	OLIVER	3.770	2.743	0.492	0.200	0.009	0.004	0.920
340	PIGEON	11.900	1.455	0.784	0.0	0.058	0.015	1.950
342	TIPPECANOE	6.050	2.756	0.421	0.0	0.019	0.005	0.200
344	WAWASEE	5.000	3.442	0.332	0.400	0.012	0.003	0.210
345	WEBSTER	11.500	1.783	0.602	0.0	0.025	0.005	0.790
346	WESTLER	10.700	1.852	0.575	0.0	0.035	0.013	0.860
347	WHITEWATER	33.100	0.757	1.200	0.0	0.084	0.012	1.620
348	WINONA	11.200	1.405	0.846	0.0	0.035	0.011	1.250
349	WITMER	11.900	1.516	0.738	0.0	0.035	0.011	0.900
393	ATWOOD	16.400	0.965	1.228	0.300	0.031	0.005	0.205
395	BERLIN	15.500	0.879	1.424	1.400	0.042	0.006	0.900
396	BUCKEYE	186.600	0.254	0.937	5.360	0.179	0.020	0.380
397	CHARLES MILL	67.100	0.445	1.722	0.0	0.127	0.011	0.465
398	DEERCREEK	9.890	0.759	1.889	1.100	0.048	0.036	2.980
399	DELAWARE	10.840	0.404	3.785	0.500	0.086	0.024	2.340
400	DILLON	27.400	0.475	2.673	0.700	0.163	0.037	1.590
401	GRANT	40.500	0.348	3.555	2.800	0.113	0.019	0.570
402	HOLIDAY	55.400	0.881	0.221	0.0	0.125	0.034	0.575
403	HOOVER	13.000	0.945	1.367	0.200	0.040	0.008	1.640
406	MOSQUITO CRE	36.300	0.881	0.794	3.400	0.058	0.006	0.150
408	PLEASANT HIL	22.900	1.097	0.826	0.300	0.036	0.010	0.455
409	ROCKFORK	38.000	0.686	1.281	0.0	0.067	0.010	0.790
411	ST MARYS	79.200	0.401	1.760	6.800	0.148	0.014	0.200
	MEAN	28.148	1.187	1.327	1.295	0.088	0.029	1.301
	STD DEV	30.573	0.849	0.937	2.152	0.112	0.060	1.268
	MINIMUM	3.770	0.254	0.221	0.0	0.009	0.002	0.120
	MAXIMUM	186.600	3.749	3.785	8.000	0.704	0.398	5.730
	MEDIAN	17.250	0.881	1.076	0.200	0.060	0.012	0.895

Table C-B. Sedimimentation Data Used for Phosphorus Retention Model Calibration

ID	NAME	ST	LS	LP	LP'	RP	RP'	UP	UP'
296	Bloomington	12.860	13.512	2.170	3.251	0.310	0.539	7.746	20.193
297	Carlyle	14.500	15.685	3.000	4.255	0.390	0.570	9.590	19.875
301	Crab Orchard	10.180	10.369	2.820	3.650	0.780	0.830	13.464	18.541
302	Decatur	19.270	28.716	9.150	11.447	0.260	0.409	16.396	32.230
312	Racoon	4.444	4.771	1.170	1.552	0.280	0.457	2.333	5.052
317	Springfield	7.180	7.400	1.700	2.292	0.250	0.444	2.778	6.647
320	Vermilion	23.300	37.006	10.200	13.160	0.330	0.481	27.582	51.841
347	Whitewater	32.570	34.412	3.280	6.033	0.640	0.804	31.453	72.702
395	Berlin	71.030	76.735	5.870	11.929	0.760	0.882	69.895	164.820
396	Buckeye	3.020	3.089	0.510	0.757	0.100	0.394	0.330	1.928
397	Charles Mill	12.390	15.703	5.560	6.816	0.170	0.323	6.331	14.745
399	Delaware	13.610	16.787	12.490	13.833	0.420	0.746	37.931	47.642
401	Grant	13.190	16.085	8.510	9.797	0.150	0.262	5.004	10.049
408	Pleasant Hil	16.520	19.051	3.510	5.034	0.210	0.449	13.291	40.772
411	St Marys	6.000	6.055	0.490	0.974	0.310	0.653	0.842	3.529
	Mean	17.338	20.292	4.695	6.319	0.357	0.531	16.331	34.038
	Std Dev	16.675	18.415	3.783	4.585	0.211	0.185	18.768	41.646
	Minimum	3.020	3.089	0.490	0.757	0.100	0.262	0.330	1.928
	Maximum	71.030	75.735	12.490	13.833	0.780	0.882	69.895	164.820

Table C-C. Data Used for Model Testing

ID	NAME	STATE	TROPHIC	TYPE	LATI	LONG	AS	AD	Z	ZMAX	T.	QS
295	BALDWIN	ILL	EUTR	RES	38.220	89.870	8.000	4.6	3.100	12.200	7.900	0.392
299	CHARLESTON	ILL	EUTR	RES	39.470	88.150	1.450	2034.0	0.900	1.500	0.003	300.000
308	HORSEHOE	ILL	EUTR	RES	38.700	90.080	8.780	74.3	2.100	-1.000	1.150	1.826
310	LOU YAEGER	ILL	EUTR	RES	39.200	89.600	5.720	274.0	3.300	6.700	0.330	10.000
314	SANGCHRIS	ILL	EUTR	RES	39.630	89.470	10.930	177.9	4.000	10.000	1.200	3.333
316	SLOCUM	ILL	EUTR	NAT	42.260	88.190	0.870	21.7	1.200	1.500	0.330	3.636
321	WEEMATUK	ILL	EUTR	RES	40.530	90.150	2.380	47.1	1.800	6.100	0.450	4.000
341	SYLVAN	IND	EUTR	RES	41.480	85.370	2.550	84.9	4.300	11.000	0.440	9.773
394	BEACH CITY	OHIO	EUTR	RES	40.630	81.500	1.700	775.0	1.200	3.000	0.008	146.341
407	OSHAUGHNESSY	OHIO	EUTR	RES	40.160	83.120	3.350	2532.0	4.800	15.500	0.025	192.000
410	SHAWNEE	OHIO	EUTR	NAT	39.650	83.780	0.770	27.2	2.500	7.600	0.200	12.500
494	AHQUABI	IOWA	EUTR	RES	41.280	93.590	0.530	12.3	3.000	6.600	0.720	4.167
495	BIG CREEK	IOWA	EUTR	RES	41.800	93.750	3.440	200.2	6.700	15.500	0.740	9.054
496	BLACKHAWK	IOWA	EUTR	NAT	42.300	95.040	3.720	56.6	1.700	3.700	0.740	2.297
500	MACBRIDE	IOWA	EUTR	RES	41.810	91.550	3.840	66.1	7.300	14.200	2.200	3.318
501	PRARIE ROSE	IOWA	EUTR	RES	41.600	95.200	0.880	19.5	3.300	8.100	1.200	2.750
503	RED ROCK	IOWA	EUTR	RES	41.420	93.070	36.220	31880.0	3.000	10.700	0.027	111.111
504	ROCK CREEK	IOWA	EUTR	RES	41.750	92.850	2.600	104.6	2.700	6.700	0.390	6.923
507	VIKING	IOWA	EUTR	RES	40.980	95.030	0.610	9.7	5.800	12.300	1.600	3.625
505	SILVER	IOWA	EUTR	NAT	43.480	93.420	1.290	6.9	1.200	1.800	1.200	1.000
	MEAN				40.817	90.139	4.981	1920.4	3.195	7.695	1.043	41.402
	STD DEV				1.356	4.123	7.910	7085.6	1.832	4.941	1.719	81.732
	MINIMUM				38.220	81.500	0.530	4.6	0.900	-1.000	0.003	0.392
	MAXIMUM				43.480	95.200	36.220	31880.0	7.300	15.500	7.900	300.000
	MEDIAN				41.130	90.115	2.575	70.2	3.000	7.150	0.585	4.083

Table C-C (cont'd). Data Used for Model Testing

ID	NAME	LP	RP	CIP	COP	UP	LN	RN	CIN	CON	UN
295	BALDWIN	0.580	0.980	1.478	0.030	19.228	7.100	0.930	18.094	1.267	5.213
299	CHARLESTON	52.510	-0.030	0.175	0.180	-8.738	2383.000	0.170	7.943	6.593	61.446
308	HORSEHOE	0.510	0.160	0.279	0.235	0.348	3.500	-1.670	1.917	5.117	-1.142
310	LOU YAEGER	3.150	0.110	0.315	0.280	1.236	46.600	0.350	4.660	3.029	5.385
314	SANGCHRIS	0.380	0.400	0.114	0.068	2.222	23.100	0.490	6.930	3.534	3.203
316	SLOCUM	11.180	0.600	3.075	1.230	5.455	31.800	0.330	8.745	5.859	1.791
321	WEEMATUK	0.610	0.530	0.152	0.072	4.511	24.600	0.350	6.150	3.998	2.154
341	SYLVAN	1.260	-0.060	0.129	0.137	-0.553	44.600	0.410	4.564	2.693	6.791
394	BEACH CITY	27.150	0.170	0.186	0.154	29.974	506.700	0.120	3.462	3.047	19.956
407	OSHAUGHNESSY	70.730	0.350	0.368	0.239	103.385	986.700	0.0	5.139	5.139	0.0
410	SHAWNEE	0.600	-0.200	0.048	0.058	-2.083	49.800	0.200	3.960	3.168	3.125
494	AHQUABI	1.020	0.670	0.245	0.081	8.460	21.400	0.620	5.136	1.952	6.798
495	BIG CREEK	2.270	0.740	0.251	0.065	25.769	107.300	0.450	11.851	6.518	7.408
496	BLACKHAWK	0.550	0.200	0.239	0.192	0.574	21.600	0.700	9.402	2.821	5.360
500	MACBRIDE	0.670	0.720	0.202	0.057	8.532	16.900	0.560	5.093	2.241	4.223
501	PRARIE ROSE	0.720	0.740	0.262	0.068	7.827	16.000	0.670	8.818	1.920	5.583
503	RED ROCK	68.960	0.610	0.621	0.242	173.789	830.000	0.260	7.470	5.528	39.039
504	ROCK CREEK	3.120	0.820	0.451	0.081	31.538	35.500	0.240	5.128	3.897	2.186
507	VIKING	0.490	0.430	0.135	0.077	2.735	7.200	0.360	1.986	1.271	2.039
505	SILVER	0.240	0.380	0.240	0.149	0.613	3.900	-0.100	3.900	4.290	-0.091
	MEAN	12.335	0.416	0.448	0.185	20.741	258.349	0.272	6.367	3.694	9.023
	STD DEV	23.357	0.325	0.688	0.257	43.265	575.196	0.519	3.688	1.655	15.198
	MINIMUM	0.240	-0.200	0.048	0.030	-8.738	3.500	-1.670	1.917	1.267	-1.142
	MAXIMUM	70.730	0.980	3.075	1.230	173.789	2383.000	0.930	18.094	6.593	61.446
	MEDIAN	0.870	0.415	0.242	0.109	4.983	28.200	0.350	5.138	3.351	4.718

Table C-C (Cont'd). Data Used for Model Testing

ID	NAME	CHLA	ZSEC	ALPH	DOWN	TPM	OPM	INM
295	BALDWIN	11.300	0.986	1.345	1.800	0.044	0.007	0.140
299	CHARLESTON	12.000	0.236	6.667	6.600	0.160	0.065	4.600
308	HORSEHOE	182.300	0.437	0.0	8.200	0.127	0.018	0.705
310	LOU YAEGER	10.700	0.264	5.963	3.600	0.186	0.076	1.600
314	SANGCHRIS	19.300	0.625	2.078	0.500	0.050	0.009	1.970
316	SLOCUM	221.100	0.323	0.0	9.200	0.805	0.302	0.200
321	WEEMATUK	8.000	0.856	1.699	0.500	0.069	0.031	1.770
341	SYLVAN	47.500	0.767	0.739	0.200	0.170	0.017	0.130
394	BEACH CITY	10.870	0.279	5.615	4.000	0.122	0.015	1.990
407	OSHAUGHNESSY	5.520	0.526	2.992	0.100	0.208	0.159	3.070
410	SHAWNEE	39.600	0.653	1.355	0.0	0.069	0.009	2.380
494	AHQUABI	8.600	0.780	1.871	6.800	0.062	0.009	0.335
495	BIG CREEK	16.900	1.562	0.556	0.200	0.046	0.011	6.470
496	BLACKHAWK	49.700	0.300	4.047	0.0	0.185	0.020	0.130
500	MACBRIDE	17.100	1.057	1.058	0.0	0.061	0.010	2.040
501	PRARIE ROSE	17.400	0.922	1.278	6.400	0.056	0.010	0.210
503	RED ROCK	14.700	0.676	2.016	1.000	0.180	0.104	1.880
504	ROCK CREEK	18.400	0.495	2.799	6.600	0.065	0.007	1.400
507	VIKING	26.000	1.041	0.814	0.800	0.075	0.017	0.130
505	SILVER	95.300	0.439	0.919	5.000	0.193	0.034	0.570
	MEAN	41.614	0.661	2.191	3.075	0.147	0.046	1.586
	STD DEV	58.945	0.342	1.950	3.216	0.166	0.072	1.656
	MINIMUM	5.520	0.236	0.0	0.0	0.044	0.007	0.130
	MAXIMUM	221.100	1.562	6.667	9.200	0.805	0.302	6.470
	MEDIAN	17.250	0.639	1.527	1.400	0.098	0.017	1.500

Appendix D

Water Quality Impact Results: Additional Interpretations and Sensitivity Analysis

Introduction

In Section 5 of this report, the application of the watershed and impoundment water quality models is discussed. The purposes of this appendix are (1) to present the details of the water quality impact results; (2) to present some supplementary interpretations of these results; and (3) to present some preliminary results of a sensitivity analysis applied to the watershed/water body model framework .

Water Quality Impact Results

The watershed and impoundment models have been applied to assess the water quality impacts of each of 11 agricultural practices on each of three field/soil types characteristic of the Black Creek Watershed, Indiana. For each practice/field/soil type combination, the analytical framework has been applied to a homogeneous watershed of 200 km^2 draining into an impoundment with a surface area of 5 km^2 and a mean depth of 4 meters. Table D-1 identifies some of the key variables used to depict the water quality impact results. These results are presented in Tables D-2, D-3 and D-4 for the lowland, ridge, and upland soil types, respectively.

TABLE D-1. DEFINITIONS OF VARIABLES IN TABLE D-2 to D-4

Number	Definition[a]	Units
1	Runoff rate	m/yr
2	Gross erosion	kg/m^2-yr
3	Sediment delivered to impoundment	kg/m^2-yr
4	Sediment trapped in impoundment	kg/m^2-yr
5	River nitrogen concentration	g/m^3
6	River phosphorus concentration	g/m^3
7	River sediment concentration	kg/m^3
8	River light extinction coefficient	m^{-1}
9	Soluble phosphorus loading	g/m^2-yr
10	Snowmelt (crop residue) phosphorus loading	g/m^2-yr
11	Available particulate phosphorus loading	g/m^2-yr
12	Total phosphorus loading	g/m^2-yr
13	Impoundment outflow nitrogen concentration	g/m^3
14	Impoundment outflow phosphorus concentration	g/m^3
15	Impoundment outflow sediment concentration	kg/m^3
16	Impoundment light extinction due to sediment[b]	m^{-1}
17	Impoundment light extinction due to color[b]	m^{-1}
18	Impoundment light extinction due to algae[b]	m^{-1}
19	Total impoundment light extinction[b]	m^{-1}
20	Secchi disc transparency[b]	m
21	Annual average impoundment light extinction coefficient	m^{-1}
22	Nitrogen resistance to algal growth[b]	$(g\text{-Chl-a}/m^3)^{-1}$
23	Phosphorus resistance to algal growth[b]	$(g\text{-Chl-a}/m^3)^{-1}$
24	Light resistance to algal growth[b]	$(g\text{-Chl-a}/m^3)^{-1}$
25	Total resistance to algal growth[b]	$(g\text{-Chl-a}/m^3)^{-1}$
26	Chlorophyll-a concentration[b]	$g\text{-Chl-a}/m^3$
27		

a - Annual average values unless otherwise noted.

b - Summer average values.

TABLE D-2. WATER QUALITY RESPONSE TO PRACTICES FOR LOWLAND SOIL

PRACTICE: * Variable	1 1CC-CV	2 1CC-CH	3 1CC-NT	4 1CB-CV	5 1CB-CH	6 1CB-NT	7 1CB*H	8 1CB*H-NT	9 1CC-CVT	10 1CC-CHT	11 1CB-NTT
1	0.178	0.178	0.178	0.178	0.178	0.178	0.142	0.142	0.178	0.178	0.178
2	0.762	0.345	0.200	0.780	0.436	0.327	0.123	0.078	0.541	0.245	0.232
3	4.957	2.322	1.373	5.070	2.904	2.205	0.861	0.550	3.574	1.672	1.587
4	4.763	2.228	1.316	4.871	2.787	2.115	0.825	0.527	3.431	1.602	1.521
5	11.076	11.076	16.272	7.836	7.836	9.660	5.592	5.796	10.248	10.248	9.240
6	0.186	0.196	0.214	0.185	0.179	0.201	0.141	0.145	0.167	0.179	0.194
7	0.496	0.232	0.137	0.507	0.290	0.221	0.086	0.055	0.357	0.167	0.159
8	47.477	26.002	20.507	49.224	30.411	26.335	12.557	10.539	35.887	20.678	21.415
9	1.105	1.175	1.383	1.092	1.138	1.264	1.045	1.099	1.120	1.189	1.280
10	0.0	0.314	0.500	0.0	0.200	0.360	0.224	0.252	0.0	0.332	0.384
11	0.750	0.373	0.261	0.757	0.451	0.383	0.144	0.097	0.547	0.271	0.278
12	1.856	1.861	2.144	1.849	1.790	2.007	1.413	1.448	1.667	1.792	1.942
13	5.443	5.443	6.664	4.432	4.432	5.032	3.552	3.640	5.208	5.208	4.901
14	0.093	0.115	0.144	0.092	0.105	0.125	0.095	0.104	0.093	0.117	0.128
15	0.019	0.009	0.006	0.020	0.012	0.009	0.004	0.002	0.014	0.007	0.007
16	0.551	0.269	0.163	0.563	0.332	0.256	0.104	0.067	0.404	0.196	0.187
17	0.520	0.610	0.852	0.495	0.557	0.740	0.509	0.571	0.536	0.630	0.773
18	0.663	0.770	0.851	0.648	0.718	0.788	0.699	0.722	0.671	0.780	0.799
19	1.773	1.698	1.926	1.750	1.648	1.824	1.352	1.399	1.652	1.646	1.799
20	0.936	0.983	0.962	0.948	1.007	0.910	1.228	1.166	1.005	1.008	0.923
21	3.252	2.676	3.115	3.226	2.709	3.028	1.879	1.953	2.862	2.520	2.920
22	3.066	3.086	2.520	3.790	3.790	3.338	4.729	4.615	3.225	3.225	3.427
23	26.661	21.426	17.049	26.997	23.450	19.633	24.943	23.627	26.673	21.037	19.232
24	15.532	14.475	15.256	15.480	14.531	15.103	13.231	13.337	14.799	14.214	14.904
25	45.279	38.986	34.335	46.267	41.771	38.074	42.902	41.579	44.697	38.476	27.563
26	0.022	0.025	0.029	0.022	0.024	0.026	0.023	0.024	0.022	0.026	0.027
27	22.304	22.875	6.489	24.350	24.604	16.649	14.491	13.915	19.064	19.635	13.049

* See Table D-1 for Variable Definitions.

TABLE D-3. WATER QUALITY RESPONSE TO PRACTICES FOR RIDGE SOIL

PRACTICE: *Variable	1 2CC-CV	2 2CC-CH	3 2CC-NT	4 2CB-CV	5 2CB-CH	6 2CB-NT	7 2CBWH	8 2CBWH-NT	9 2CC-CVT	10 2CC-CHT	11 2CB-NTT
1	0.064	0.042	0.019	0.064	0.042	0.019	0.022	0.013	0.064	0.042	0.019
2	2.049	0.927	0.537	2.098	1.171	0.878	0.332	0.210	1.455	0.658	0.623
3	11.065	5.360	3.262	11.307	6.631	5.103	2.102	1.375	6.084	3.527	3.739
4	10.729	5.181	3.145	10.964	6.415	4.931	2.022	1.321	7.828	3.789	3.607
5	18.460	19.460	21.980	13.060	13.060	14.740	8.700	8.700	17.080	17.080	14.040
6	0.139	0.131	0.157	0.134	0.125	0.139	0.089	0.084	0.118	0.121	0.132
7	1.107	0.536	0.326	1.131	0.663	0.510	0.210	0.138	0.808	0.393	0.374
8	95.228	46.748	29.035	97.175	57.313	44.189	18.685	12.339	70.009	34.705	32.759
9	0.408	0.403	0.387	0.401	0.357	0.362	0.380	0.358	0.421	0.416	0.368
10	0.0	0.314	0.628	0.0	0.200	0.360	0.224	0.264	0.0	0.332	0.428
11	0.969	0.590	0.552	0.956	0.658	0.672	0.289	0.223	0.754	0.463	0.526
12	1.376	1.308	1.568	1.358	1.246	1.394	0.893	0.844	1.175	1.210	1.323
13	7.080	7.030	7.663	5.956	5.956	6.343	4.727	4.727	6.623	6.623	6.186
14	0.046	0.063	0.089	0.045	0.055	0.069	0.056	0.056	0.047	0.065	0.073
15	0.034	0.018	0.012	0.034	0.022	0.017	0.008	0.005	0.026	0.014	0.013
16	0.953	0.510	0.333	0.971	0.612	0.489	0.226	0.154	0.725	0.390	0.374
17	0.111	0.112	0.124	0.100	0.090	0.076	0.076	0.060	0.123	0.126	0.092
18	0.410	0.543	0.706	0.398	0.461	0.577	0.495	0.500	0.423	0.559	0.603
19	1.514	1.205	1.202	1.510	1.222	1.181	0.837	0.754	1.312	1.116	1.109
20	1.097	1.378	1.390	1.100	1.358	1.406	1.982	2.201	1.266	1.488	1.496
21	3.232	1.906	1.411	3.254	2.143	1.733	0.948	0.682	2.585	1.589	1.439
22	2.372	2.372	2.191	2.820	2.820	2.648	3.553	3.553	2.461	2.461	2.715
23	55.368	39.643	27.732	57.010	45.884	36.359	45.052	44.689	54.087	38.350	34.412
24	15.491	13.269	12.595	15.536	13.619	13.025	12.023	11.718	14.321	12.830	12.632
25	73.231	55.284	42.518	75.365	62.323	52.232	60.628	59.959	70.870	53.641	49.759
26	0.014	0.018	0.024	0.013	0.016	0.019	0.016	0.017	0.014	0.019	0.020
27	23.562	24.133	20.051	25.818	26.072	25.134	17.120	17.367	20.322	20.893	21.534

* See Table D-1 for Variable Definitions.

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TABLE D-4. WATER QUALITY RESPONSE TO PRACTICES FOR UPLAND SOIL

PRACTICE: *Variable	1 3CC-CV	2 3CC-CH	3 3CC-NT	4 3CB-CV	5 3CB-CH	6 3CB-NT	7 3CBWH	8 3CBWH-NT	9 3CC-CVT	10 3CC-CHT	11 3CB-NTT
1	0.127	0.105	0.083	0.127	0.105	0.063	0.076	0.072	0.127	0.105	0.083
2	5.953	2.693	1.539	6.095	3.402	2.551	0.964	0.609	4.227	1.512	1.811
3	33.927	15.867	9.430	34.701	19.839	15.069	5.983	3.885	24.426	11.447	10.873
4	32.779	15.315	9.091	33.529	19.155	14.543	5.761	3.736	23.591	11.041	10.487
5	12.560	12.560	15.600	9.472	9.472	10.460	6.512	6.832	11.456	11.456	9.936
6	0.095	0.099	0.147	0.088	0.089	0.129	0.071	0.077	0.078	0.091	0.116
7	3.393	1.587	0.943	3.470	1.984	1.507	0.598	0.389	2.443	1.145	1.087
8	290.040	136.599	82.651	296.508	170.137	129.991	52.211	34.620	209.338	99.103	94.442
9	0.325	0.363	0.516	0.307	0.332	0.427	0.366	0.409	0.326	0.364	0.429
10	0.0	0.256	0.494	0.0	0.162	0.320	0.185	0.220	0.0	0.270	0.340
11	0.625	0.375	0.472	0.575	0.392	0.542	0.162	0.137	0.452	0.272	0.395
12	0.950	0.993	1.472	0.883	0.886	1.290	0.712	0.766	0.778	0.907	1.164
13	5.833	5.833	6.526	4.974	4.974	5.275	3.935	4.061	5.547	5.547	5.115
14	0.013	0.026	0.054	0.012	0.020	0.035	0.033	0.042	0.014	0.030	0.040
15	0.115	0.055	0.034	0.117	0.068	0.053	0.022	0.015	0.094	0.041	0.039
16	3.252	1.565	0.959	3.324	1.937	1.491	0.628	0.421	2.366	1.150	1.095
17	0.159	0.166	0.241	0.148	0.144	0.183	0.129	0.153	0.164	0.173	0.194
18	0.105	0.237	0.459	0.094	0.175	0.308	0.307	0.379	0.123	0.275	0.351
19	3.556	2.008	1.699	3.606	2.296	2.022	1.104	0.993	2.693	1.638	1.680
20	0.467	0.827	0.977	0.460	0.723	0.821	1.503	1.672	0.616	1.013	0.989
21	10.274	5.233	3.639	10.456	6.283	5.061	2.311	1.762	7.630	4.008	3.909
22	2.879	2.879	2.573	3.377	3.377	3.184	4.269	4.137	3.028	3.028	3.283
23	233.870	102.967	46.432	264.661	143.020	74.052	79.441	61.934	206.485	88.736	65.279
24	50.000	20.730	16.331	50.000	25.201	20.144	13.877	13.066	34.843	17.173	16.939
25	286.749	126.577	65.335	318.037	171.598	97.380	97.587	79.137	244.356	108.937	85.501
26	0.003	0.008	0.015	0.003	0.006	0.010	0.010	0.013	0.004	0.009	0.012
27	12.835	13.406	6.855	17.459	13.713	12.153	5.552	3.829	9.595	10.166	8.552

* See Table D-1 for Variable Definitions.

Additional Interpretations

In Section 2 the primary implications of the results are discussed. Of particular interest is the apparent attenuation of the effects of erosion control on water quality, as the analysis moves downstream from the river into the impoundment and when components other than sediment are considered. A possible conflict between the water quality management goals of controlling both sedimentation and eutrophication using these types of practices has also been discussed in Section 2. Additional interpretations of the impacts of the various practices and soil types on eutrophication can be derived from Figs. D-1, D-2, and D-3.

In Fig. D-1, the three components of phosphorus loading (available particulate, soluble, and crop residue) are depicted for each soil type and practice. The importance of residue phosphorus leached by snowmelt is apparent in the practices involving reduced tillage, despite the fact that leaching of only 1 percent of the available residue phosphorus has been assumed. As noted in Appendix B, laboratory studies suggest that one freezing-thawing-leaching cycle could release from 5 to 28 percent of the phosphorus in various crop residues. The importance of the soluble phosphorus component is apparent in the relatively flat, phosphorus-rich, lowland soils. In general, impacts of the various practices on available phosphorus loadings are considerably different (in magnitude and often in sign) from the impacts on soil loss.

The components of the mean summer light extinction coefficients in the impoundment are displayed for the different practices and soil types in Fig. D-2. Extinction coefficients are inversely proportional to Secchi

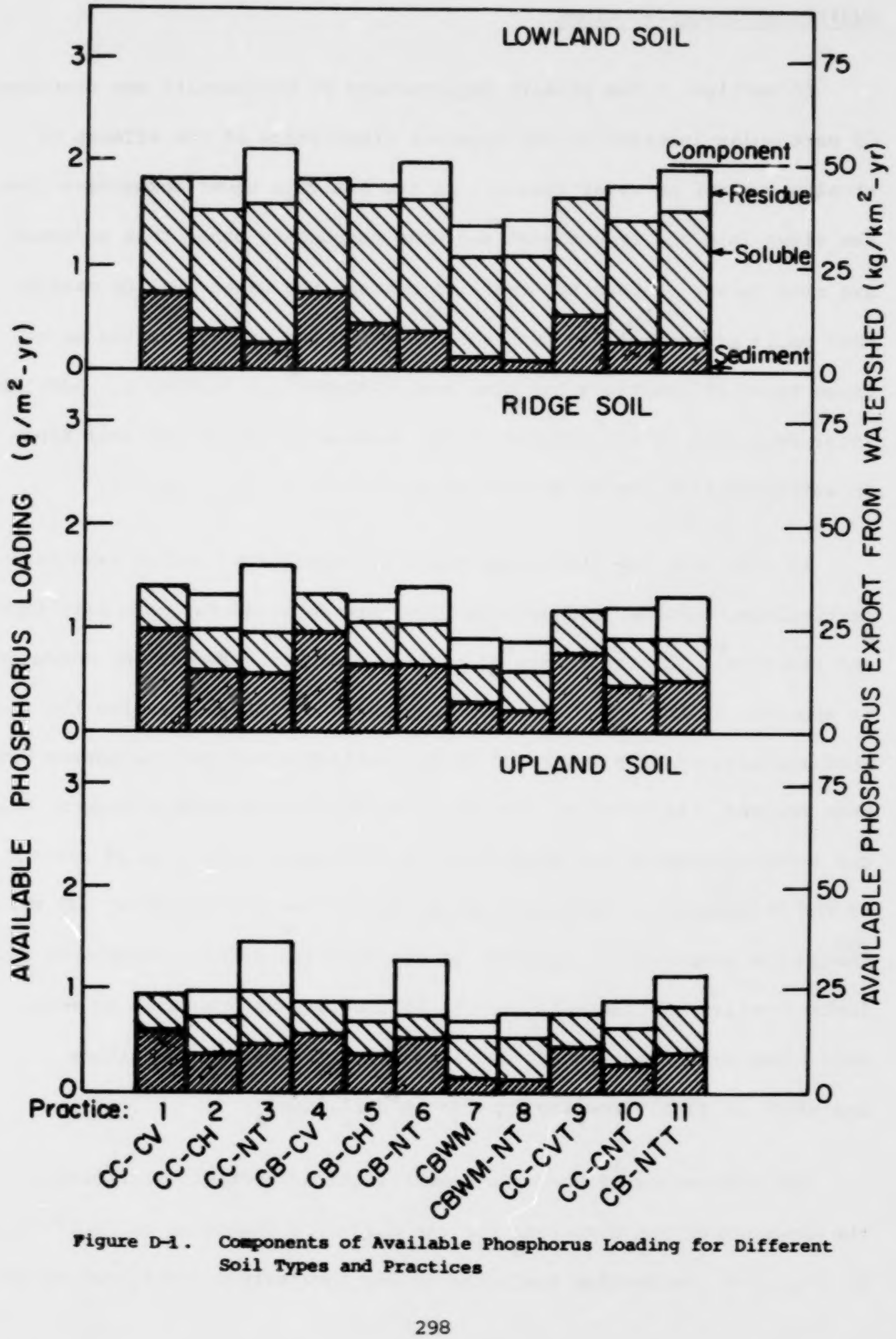


Figure D-1. Components of Available Phosphorus Loading for Different Soil Types and Practices

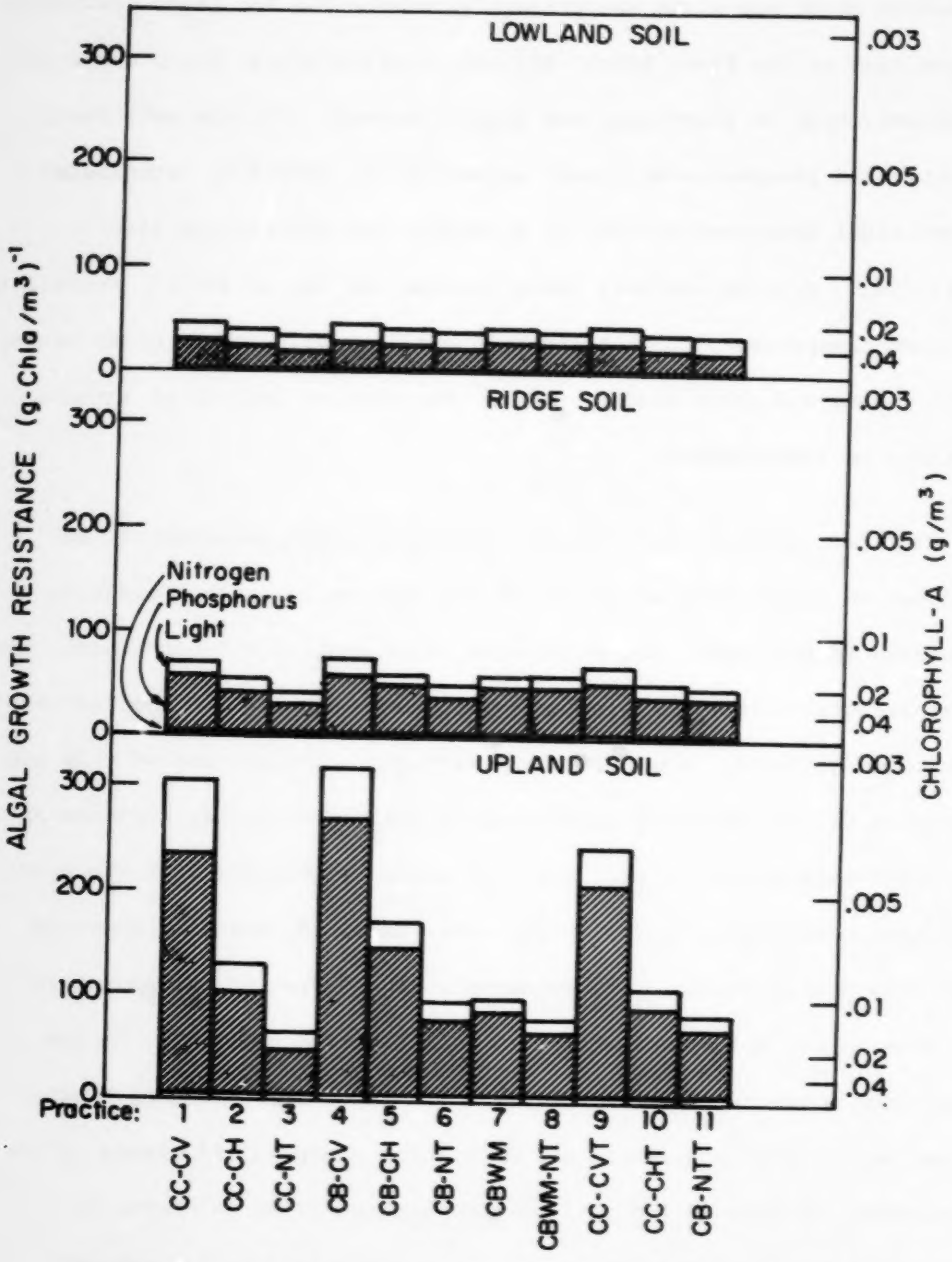


Figure D-3. Components of Algal Growth Resistance for Different Soil Types and Practices disc transparencies, which are noted on the right-hand scales of Fig. D-2. Dissolved color and algae are primarily responsible for light extinction in the case of the flat, poorly-drained, lowland soils, which are also relatively high in phosphorus and organic matter. For the relatively erodible and phosphorus-deficient upland soils, turbidity (attributed to non-algal suspended solids) is primarily responsible for light extinction. Erosion controls cause substantial (up to 4-fold) increases in water transparency only in the upland soil case. In the other cases, algal growth and color tend to reduce the relative impacts of erosion controls on transparency.

Fig. D-2 depicts the limiting effects of light, phosphorus, and nitrogen on impoundment algal growth for each soil type and practice. According to the model used to predict chlorophyll-a concentrations, the total resistance to algal growth is computed as the sum of the resistances attributed to light, phosphorus, and nitrogen. The inverse of this sum is a measure of the potential chlorophyll-a concentration, as depicted on the right-hand scales of Fig. D-3. In general, phosphorus is the most important controlling factor in all cases examined, while nitrogen is generally insignificant. The relatively high degree of phosphorus resistance in the upland soil cases reflect the effects of (1) the low phosphorus contents of those soils and (2) their relatively high erosion rates, which tend to increase the phosphorus trapping efficiency of the impoundment because of the influence of sedimentation on phosphorus settling velocity (see Appendix C). In the upland soils, erosion controls generally cause less resistance to downstream algal growth both with regard to phosphorus and to light. In the cases of lowland and ridge soils, however, chlorophyll-a levels are not influenced substantially by the practices examined.

These results indicate the relative impacts of these agricultural practices on impoundment eutrophication are small, except in the extreme upland soil case, in which a 10-fold decrease in soil loss results in a 4-fold increase in algal biomass (comparing practices CB-CV and CBWH-NT) These conclusions primarily result from the following factors:

(1) a generally small fraction (5 to 10) of the particulate phosphorus in soils is biologically available (acid extractable);

(2) reduced tillage alternatives create a potential for leaching of phosphorus from crop residues during snowmelt periods and cause enrichment in surface soil phosphorus levels;

(3) the phosphorus trapping efficiency of an impoundment appears to be a strong positive function of sedimentation rate; and

(4) algal growth is sensitive to available light and is therefore stimulated by reductions in ambient turbidity levels.

An improved picture of the effects of erosion controls and other agricultural practices on impoundment eutrophication could be derived by obtaining more accurate, quantitative definitions of the above relationships through additional data compilation and analysis. Interpretation of the water quality effects of eutrophication could be enhanced by expanding the impoundment model to permit direct estimation of dissolved oxygen levels, as influenced by external and internal sources of oxygen demand.

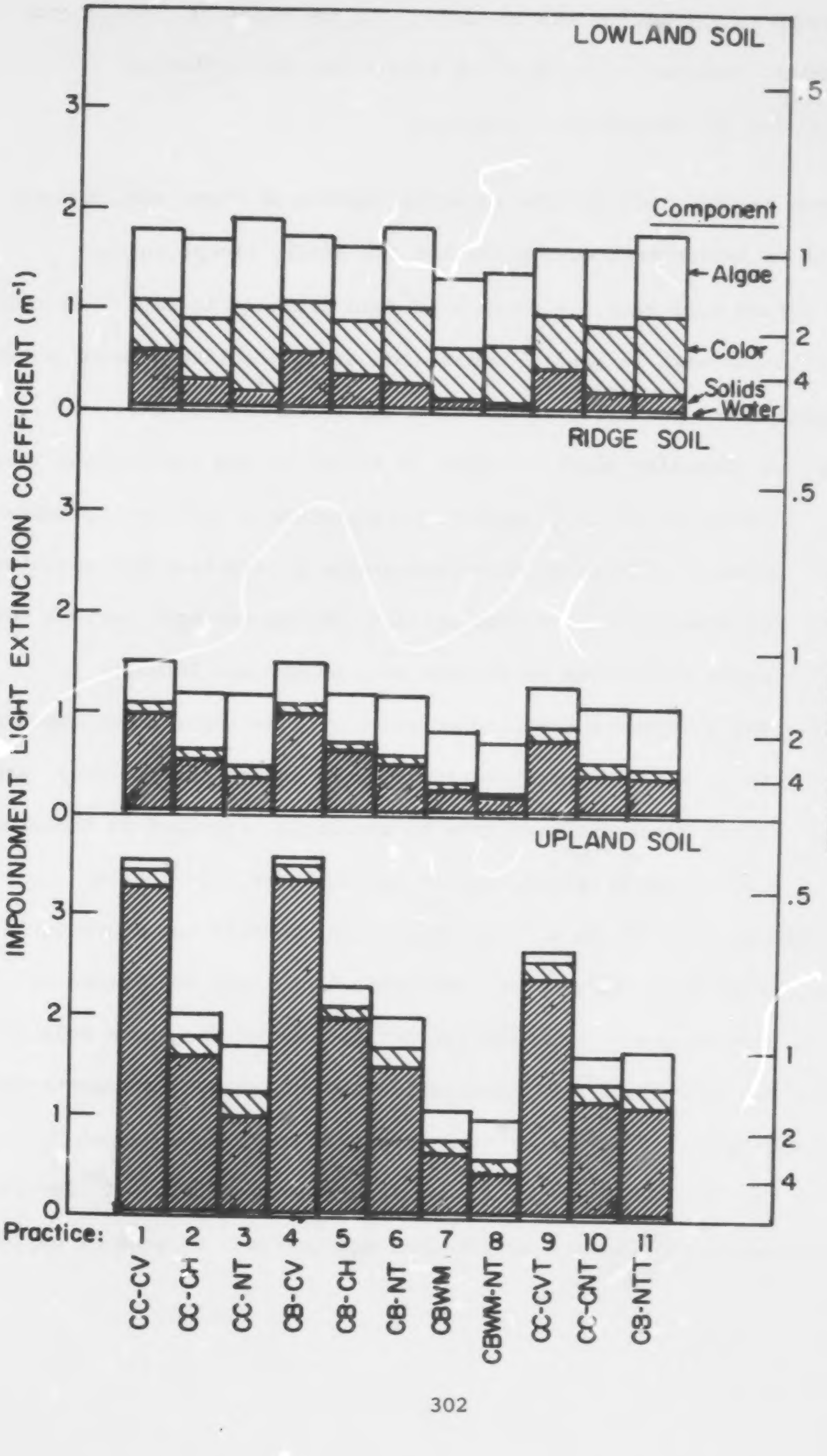


Figure D-2. Components of Impoundment Light Extinction for Different Types and Practices

Sensitivity analysis

One of the advantages of utilizing a framework of relatively simple models for evaluating water quality impacts is that it facilitates sensitivity and error analyses. These help to identify key structural or parametric assumptions, as well as guide further model development by indicating the most fruitful areas for investment of additional data collection and analytical resources. For a given total investment, the "most fruitful" area for further work would be that which results in the greatest degree of improvement in the accuracy of the model or model framework. Specific strategies for implementing sensitivity and error analyses have been discussed in detail by Thomas (1965) and Walker (1977). As model complexity increases, the size, expense of implementation, and increasing effects of data errors tend to reduce both the feasibility and the benefits of performing these types of analyses.

Relatively crude, initial applications of these methods to the water quality model framework developed and applied in this project are described below. They demonstrate the feasibility and benefits of conducting sensitivity and error analyses within our model framework. This means that they indicate those components within the model framework which are most important to evaluating both the absolute and the relative impacts of these agricultural practices on water quality.

At a basic level, a marginal sensitivity analysis would involve evaluating and ranking the first partial derivatives of the predicted variables with respect to the parameter estimates:

$$S_{ijk} = \frac{\theta_k}{Y_{ij}} \frac{\delta Y_{ij}}{\delta \theta_k} = \frac{\delta \ln Y_{ij}}{\delta \ln \theta_k} \qquad (1)$$

where, S_{ijk} = sensitivity coefficient for predicted variable i, case j, and parameter k

θ_k = nominal value of parameter k

Y_{ij} = nominal value of predicted variable i for case j

Defined in this way, a sensitivity coefficient equals the percent increase in the predicted variable resulting from a 1 percent increase in a given parameter value. While these derivatives can be evaluated analytically for simple models, finite-difference methods are usually easier to implement if the model is computerized. For a given case (e.g., soil type/agricultural practice combination) and variable, the parameters can be ranked according to decreasing absolute values of the sensitivity coefficients. This provides a preliminary indication of which parameters or processes are most important in determining the prediction.

This strategy has been implemented for a total of 12 predicted variables, 33 cases (3 soil types x 11 practices), and 38 parameters. The parameters, which characterize the various processes represented in the watershed and impoundment models, are listed in Table D-5 along with their nominal values and equation references. To illustrate the methodology, results are presented and discussed below for 2 predicted variables and 9 cases (3 soil types x 3 practices).

The ranked sensitivity coefficients for the five most critical parameters in each case are presented in Tables D-6 and D-7 for predictions of impoundment light extinction coefficients and chlorophyll-a levels, TABLE D-5. PARAMETERS INCLUDED IN SENSITIVITY ANALYSIS

Watershed Model (Appendix B)			Impoundment Model (Appendix C)		
Symbol	Value	Equation	Symbol	Value	Equation
R	160	(1)	K_S	clay 50	(3)
K_1	.50	(3)		silt 120	
K_2	20.	(4)		sand 8000	
K_3	2.	(6)	a_0	.377	(11)
d_{CL}	1.67	(7)	a_1	-.779	(11)
d_{SI}	1.00	(8)	a_2	.222	(11)
d_{SA}	.33	(9)	a_3	0.0	(11)
K_4	.34	(10)	a_4	1.201	(11)
K_5	.20	(11)	c_o	.223	(23)
q	.25	(13)	c_1	-.445	(23)
q^o_R	.178	(14)	c_2	.351	(23)
	.064				
	.127 *		c_3	.862	(23)
K_6	2.0	(17)	c_4	0.0	(23)
C_D	.03	(23)	ε_w	.04	(27)
γ_p	1.0 *	(24)	k_s	.085	(28)
	1.0				
	.50		k_B	30.	(29)
K_7	.01	(26)	K_C	6.0	(33)
F_D	.7 *	(29)	F_{CS}	3.0	(39)
	.5				(40)
	.6		K_L	.44	(51)
K_8	.5	(31)	f_L	1.363	(65)
γ_c	10.	(33)	f_p	1.866	(65)
			f_n	1.866	(65)

* Parameter values for lowland, ridge, and upland soils, respectively.

TABLE D-6. EXTINCTION COEFFICIENT SENSITIVITIES*

Soil Type	Rank	Practice					
		(1 CC-CV)		(5 CB-CH)		(7 CBWM)	
		Param.	Sens.	Param.	Sens.	Param.	Sens.
Lowland	1	F_{cs}	-.55	F_{cs}	-.49	q_r^o	.51
	2	q_r^o	.37	q_r^o	.43	F_{cs}	-.42
	3	K_5	-.31	γ_c	-.31	k_B	.36
	4	K_4	.29	k_B	.28	γ_c	-.35
	5	k_s	.28	f_p	-.24	q	-.31
Ridge	1	F_{cs}	-.67	F_{cs}	-.55	k_B	.47
	2	K_5	-.66	K_5	-.53	f_p	-.44
	3	K_4	.63	K_4	.50	F_{cs}	-.35
	4	k_s	.61	k_s	.48	K_5	-.35
	5	a_4	-.46	a_4	-.46	a_4	-.33
Upland	1	K_5	-.95	F_{cs}	-.88	F_{cs}	-.67
	2	F_{cs}	-.95	K_5	-.85	k_s	.57
	3	k_s	.91	k_s	.83	K_5	-.54
	4	K_4	.91	K_4	.80	K_4	.51
	5	R	.84	R	.73	R	.43

* A sensitivity coefficient represents the percent increase in the predicted value resulting from a 1 percent increase in the respective parameter.

respectively. For the extinction coefficients, Tables D-6 indicates the importance of the assumed ratio of summer-average to mean-annual

TABLE D-7. CHLOROPHYLL-A SENSITIVITIES *

Soil Type	Rank	Practice					
		1 (CC-CV)		5 (CB-CH)		7 (CBWM)	
		Param.	Sens.	Param.	Sens.	Param.	Sens.
Lowland	1	a_4	-.75	f_p	-.56	f_p	-.58
	2	f_p	-.59	a_4	-.50	γ_p	-.39
	3	a_1	.54	K_L	.46	K_L	.37
	4	K_L	.48	a_1	.42	q	-.37
	5	f_L	-.34	f_L	-.35	a_1	.32
Ridge	1	a_4	-1.68	a_4	-1.17	f_p	-.74
	2	a_1	.96	a_1	.77	a_4	=.57
	3	f_p	-.75	f_p	-.73	a_1	.52
	4	a_o	-.53	a_o	-.43	q	-.31
	5	K_L	.30	K_L	.27	a_o	-.29
Upland	1	a_4	-3.83	a_4	-2.81	a_4	-1.25
	2	a_1	1.61	a_1	1.36	a_1	.86
	3	a_o	-.89	f_p	-.83	f_p	-.81
	4	f_p	-.81	a_o	-.75	a_o	-.48
	5	K_5	.32	K_5	.56	C_D	.26

* A sensitivity coefficient represents the percent increase in the predicted value resulting from a 1 percent increase in the respective parameter.

suspended solids and color concentrations (F_{cs}), delivery ratio parameters (K_5 and K_4) and the slope of the extinction coefficient versus suspended solids concentration (k_S). Sensitivity rankings vary somewhat with soil type and practice. For example q_R^o and γ_c appear to be important only in the lowland soil, which has a relatively high color contribution. The chlorophyll-a sensitivity rankings suggestion the importance of the phosphorus trapping parameters (a_4, a_1, a_0) and the parameters of the biomass model (f_P, K_L, f_L). The listing of only five parameter sensitivity coefficients for each case does not imply that the remaining should be ignored, but serves here as an illustration.

A modification of the above procedure has been implemented by estimating the sensitivities of the relative magnitudes of the predicted variables to the assumed parameter values. Relative sensitivity coefficients are of the form :

$$S^R_{ijk} = \frac{\theta_k}{Y_{ij}} \frac{\delta Y_{ij}}{\delta \theta_k} - \frac{\theta_k}{Y_{io}} \frac{\delta Y_{io}}{\delta \theta_k}$$

$$= \frac{\delta \ln (Y_{ij}/Y_{io})}{\delta \ln \theta_k}$$

The relative magnitude of any predicted variable is defined as Y_{ij}/Y_{io}, the ratio of the value for a given case to the value for an assumed base case. A sensitivity coefficient evaluated as prescribed above represents the percent increase in that ratio resulting from a 1 percent increase in a given parameter value. When the model framework is being used to compare practices, these relative sensitivity coefficients are perhaps more important to consider than are the absolute versions. Parameters have been ranked according to this scheme using practice 1 (continuous corn with conventional tillage) as a base case for each soil type.

Results are presented in Tables D-8 and D-9 for predictions of extinction coefficients and chlorophyll-a levels, respectively. In comparing these

TABLE D-8. EXTINCTION COEFFICIENT SENSITIVITY* RELATIVE TO PRACTICE 1

Soil Type	Rank	Practice			
		5 (CB-CH)		7 (CBWM)	
		Parameter	Sensitivity	Parameter	Sensitivity
Lowland	1	K_5	.11	K_5	.22
	2	K_4	-.10	K_4	-.21
	3	k_s	-.10	k_s	-.21
	4	R	-.10	R	-.18
	5	d_{CL}	-.09	d_{CL}	-.18
Ridge	1	K_5	.13	k_S	-.35
	2	k_S	-.13	F_{cs}	.33
	3	F_{cs}	.13	K_5	.31
	4	K_4	-.12	K_4	-.30
	5	R	-.12	k_B	.26
Upland	1	R	-.11	K_5	.41
	2	K_5	.11	R	-.41
	3	K_4	-.10	K_4	-.39
	4	a_4	-.10	k_S	-.35
	5	k_S	-.08	F_{cs}	.28

* A sensitivity coefficient represents the percent increase in the predicted value resulting from a 1% increase in the respective parameter.

results with those in Tables D-6 and D-7, two general observations can be made First, the lists of most important parameters change somewhat as the ranking criteria switches from absolute to relative sensitivities. Secondly, the relative sensitivity coefficients are generally lower in scale. This essentially reflects that the model framework is more

TABLE D-9. CHLOROPHYLL-A SENSITIVITY* RELATIVE TO PRACTICE 1

Soil Type	Rank	Practice			
		5 (CB-CH)		7 (CBWM)	
		Parameter	Sensitivity	Parameter	Sensitivity
Lowland	1	a_4	.25	a_4	.46
	2	a_1	-.12	a_1	-.22
	3	a_o	.07	a_o	.12
	4	K_7	.06	K_L	-.11
	5	F_D	-.04	q	-.11
Ridge	1	a_4	.52	a_4	1.12
	2	a_1	-.19	a_1	-.44
	3	K_7	.12	a_o	.24
	4	a_o	.10	K_7	.20
	5	d_{SI}	.07	d_{SI}	.16
Upland	1	a_4	1.02	a_4	2.58
	2	K_L	.33	a_1	-.76
	3	a_1	-.25	a_o	.42
	4	K_5	.24	K_7	.23
	5	K_4	-.23	K_L	.18

* A sensitivity coefficient represents the percent increase in the predicted value resulting from a 1% increase in the respective parameter.

accurate for estimating the relative impacts of the various practices than for estimating the absolute impacts.

For estimating extinction coefficients in a relative sense, the most important parameters appear to be those related to sediment delivery (K_S, K_Y, d_{CL}), rainfall erosivity (R), and suspended solids light extinction (k_S). Note that F_{CS} is considerably less important here, than when the parameters are ranked according to absolute sensitivities (Table D-6). This suggests that a given percent error in the estimate of this parameter would have a nearly constant percentage impact on the computed values of the light extinction coefficients for the various practices. This impact is subtracted out when relative sensitivities are considered. In evaluating relative chlorophyll-a levels (Table D-9), the phosphorus trapping parameters appear to be most important, along with the leached fraction of crop residue phosphorus, K_7.

Based upon interpretations of the results of the above sensitivity analyses, the most important parameters and processes for estimating the relative impacts of agricultural practices according to various criteria are summarized in Table D-10. The sensitivity rankings are typical of the various soil types and practices considered. They provide tentative indications of the most important areas for future model improvement. At a higher level of sophistication, parameters could be ranked based upon their respective contributions to the total variance of predictions derived from the model. Such an error analysis could alter, somewhat, the rankings presented in Table D-10. The merits of such an analysis should be explored in follow-up work.

TABLE D-10. SUMMARY OF MOST IMPORTANT MODEL PARAMETERS FOR ESTIMATING THE RELATIVE WATER QUALITY IMPACTS OF VARIOUS AGRICULTURAL PRACTICES

Criteria	Parameters	Processes
River Sediment Concentration & Impoundment Sedimentation	d_{CL}, d_{SI}	sediment delivery
	K_1 , K_3	texture enrichment
River Phosphorus Concentration & Impoundment Phosphorus Loading	K_5, K_4	sediment delivery
	K_7	residue leaching
	R	rainfall erosivity/ gross erosion
Impoundment Nitrogen Concentration	C_3, C_o, C_1	nitrogen trapping
	q	total flow
	F_D	denitrification
River Light Extinction Coefficient	d_{CL}, d_{SI}, K_5, K_4	sediment delivery
	K_1	texture enrichment
	R	rainfall erosivity/ gross erosion
	k_s	solids light extinction
Impoundment Phosphorus Concentration	a_4, a_o, a_1	phosphorus trapping
	K_7	residue leaching
Impoundment Sediment Concentration	d_{SI}, d_{CL}	sediment delivery
	K_s	sediment trapping
Impoundment Color Concentration	K_8	soil organic matter enrichment
	K_1, K_3	texture enrichment
Impoundment Light Extinction Coefficient	K_5, K_4, d_{CL}	sediment delivery
	k_s	solids light extinction
	F_{cs}	seasonal variations in color and suspended solids concentrations
Chlorophyll-a	a_4, a_o, a_1	phosphorus trapping
	K_7	residue leaching
	K_L	algal growth

REFERENCES, APPENDIX D

Thomas, H.A., Jr. "Operations Research in Disposal of Liquid Radioactive Wastes in Streams", Harvard Water Resources Group, Cambridge, MA, Dec. 1965.

Walker, W.W., Jr. "Some Analytical Methods Applied to Lake Water Quality Problems" Ph.d. Thesis, Engineering, Harvard University, (University Microfilms, Ann Arbor, MI), 1977.

Appendix E

Discussion of Benefit Estimation

This appendix presents the results of the literature review and work on benefit estimation. The discussion follows the outline described in Table E-1.

Introduction

We begin by emphasizing several points frequently made. As is generally agreed upon among economists willingness-to-pay is the appropriate measure of benefits. The choice facing society is not between clear water and polluted water, for example, but between various levels of pollution. It is the incremental or marginal values that are important in making decisions. The "demand" for water quality (the analog to market demand) is the aggregate of how much individuals will give up (will pay) to enjoy additional increments of improved water quality.

The economic theory for valuing benefits is well developed. A complete theory on the provision and use of public goods, those which are enjoyed in common, such as the water quality of a stream, has been developed. From the literature of welfare economics we get such concepts as the Pareto Optimum criteria, consumer surplus, the social welfare function,

Table E-1

Outline of Benefit Estimation Discussion

1. Points from proposal
    - A. Willingness to Pay -- Appropriate Measure
    - B. Economic Theory Well Developed
    - C. Not so Easily Applied
        - 1) Lack of Market
        - 2) Problem of "Intangibles"
        - 3) Thorough Analysis Impossible
        - 4) Data Needs Immense
        - 5) Equity Question
2. EPA Needs (Our Impression)
    - A. Further Pollution Control Expenditures Assessed on Basis of Benefits
    - B. Generally Accepted Methodology
        - 1. EIS Review
        - 2. Support Regulatory Standards
    - C. Policy Direction
3. Criteria
    - A. Ease of Application (Data)
    - B. Identified Pollutants
    - C. Theoretical Validity
    - D. Pollutant -------→ Environmental (Water) Quality -------→ Value Measurement
    - E. Benefit Quantification
    - F. Distribution of Impacts
    - G. Generalizability
4. Examples

and the equi-marginal principle for selecting the appropriate level of pollution abatement.

But as is well known, these general principles for management of public goods are not so easily applied. The problems of the misallocations of resources and externalities are not theoretical but empirical ones. For instance, there is the problem of the lack of a market. As we said, public goods are enjoyed in common. They are shared, so they are not contained in market transactions and they have no market price to use to define demand. The question of intangible benefits is also complex. A hypothetical demand curve can be derived from aggregating individuals' willingess-to-pay (for increased increments of a public good, as mentioned above). One approach to estimating willingness-to-pay is to calculate the damages that would occur if a project were not undertaken. However, this method still underestimates psychic benefits (called "intangibles").

In most cases a complete, thorough analysis is impossible because it is too difficult to estimate the multitude of impacts of, say, a change in water quality even though it is said (by Kneese and others) that a materials balance concept should be used. The existence of interactions, substitutions and indirect benefits in most water quality control problems contributes to the difficulty of conducting an adequate analysis as defined by economic theory. Furthermore, data needs are immense and the expense and personnel necessary for data collection are great. These are the greatest impediments to good empirical benefit estimation work. Examples of the types of data used for the various methods of estimating water quality benefits are survey data, property sales prices, detailed studies of physical damages, and origin and destination data from travellers. Many methods use data that must be collected anew for each study.

In addition to these obstacles there is the equity question. Environmental control measures are inherently redistributive and there is no generally accepted method for the resolution of the conflict of interest among those who gain and those who lose from environmental quality improvement. This issue is addressed in Section 6 of the report.

Need for Benefit Estimation

From discussions with personnel in EPA and review of the literature including the study of water reuse and benefit estimation done by ERCO for the EPA (1977). The need for benefit estimation can be summarized as follows.

- A time may come when the national (or industry-specific) pollution control effort will reach a point at which further expenditures must be assessed on the basis of benefits received.
- There is a need to develop a generally accepted methodology for estimating project benefits; something straightforward and applicable to multiple situations including review of EIS reports.
- Regulatory standards may need to be supported by benefit estimation.

Criteria for Benefit Estimation Methods.

Meeting these needs will be a difficult task. To assist in evaluating methods of benefit estimation we developed a set of criteria which define a "satisfactory" benefit estimation framework:

A. Ease of application (availability of data).

Does the methodology rely on data generally available, such as the census and property value assessments or must it be collected systematically each time?

B. Consideration of identified pollutants.

This criteria is necessary to relate the benefit estimation to non-point source pollution control in general and, specifically, to apply it to particular management practices.

C. Theoretical validity.

This necessity was covered earlier in our discussion of willingness-to-pay. In practice, it usually means development of a demand function rather than estimation of gross benefits or use of a "judgment value" for benefits.

D. Investigation of the relationship between pollution levels and value measurement.

The reasoning behind this requirement is the same as for B above, to be specific.

E. Quantification of benefits.

To compare with marginal costs we must be able to discuss incremental benefits. We must have some measure of benefits to make a decision -- they are not infinite.

F. Identification of distribution of impacts.

This criteria concerns the equity question. We must know who gains, who loses, and the consequences of alternative controls to facilitate a decision. This is not necessary to insure national economic efficiency but it certainly is recognized as important. (See, for example, the hearings on the Principles and Standards in response to the President's concern.)

G. Generalizability of methodology.

For it to be useful to meet EPA needs, the technique must not be limited to a single problem or region.

Our assessment or benefit methodologies may show that certain techniques appear more promising than others for specific pollutants or impact groups or land/water configurations.

Examination of Examples of Benefit Studies

Having reviewed over thirty recent benefit studies we have selected eight representative to examine in detail in light of the above set of criteria.

1. Dennis P. Tihansky, "Damage Assessment of Household Water Quality," Journal of the Environmental Engineering Division, ASCE, Vol. 100, No. EE4, August 1974.

This paper develops a comprehensive framework for analysis of national mineralized water supply damages. The aggregate mineral content of water, i.e., the total dissolved solids (TDS), increases the depreciation rate of household items and adds to their maintenance needs. Tihansky derives functions relating these impacts on households to various levels of dissolved mineral constitutents in the water supply. Data from household surveys are used to derive damage relations comparing the average service life of twenty household items to TDS. For example, the average life span of toilet facilities decreases exponentially as the TDS content in water supply increases.

Tihansky defines monetary impacts as the sum of annualized capital costs plus operation, maintenance and repair (OMR) expenses. Total household damages in monetary terms are calculated from the individual household item damage equations (TDS and hardness versus dollars). Tihansky applies these damage functions to state-by-state household statistics, such as income levels, and data on water quality from USGS and municipal water supply surveys. This yields regional estimates of damages, expressed as intervals to account for variability among households and to reflect water quality sampling errors.

Significant impacts occur in the midwest and southwest. The least impact is in the south, northwest and New England. The mean per household for the United States is $33.50 per year.

The final step of the analysis consists of the calculation of the percent of damage caused by man-made as compared to natural sources of TDS load. Tihansky uses a generalized estimate of approximately thirty percent, derived from a study of the Colorado River and another of a New Jersey river.

Tihansky's analysis meets all our criteria. For data he relies on existing studies relating TDS to household item damages (A). He treats a specific pollutant (B). He develops functional relationships between damages and pollutant (C). The relationship between value measurement and levels of pollution is explicit (D). Benefits are quantified in dollars (E). The distributional aspects are addressed in terms of the differences in impacts among states and regions in the United States (F). His methodology is general enough to be applied to state and regional data (G).

2. Sharon Oster, Survey Results on the Benefits of Water Pollution Abatement in the Merrimack River Basin, Department of Economics, Yale University, September 1976. Also in Water Resources Research, October 1977.

The report deals with the estimate of benefits of water quality improvement derived from a frequency of use/willingness-to-pay survey conducted in 1974 in the Merrimack River Basin. The study consisted of a telephone survey of 200 residents of towns along the river. The questionnaire requested information on willingness to be taxed or to pay a yearly charge for the river to be cleaned up. It also asked for information on increased use of the river for recreation activities if it were cleaned up.

The results of the survey showed that the average aggregate willingness-to-pay for river clean-up is slightly over $12.00 per year. The mean increased use of a clean river is thirteen days per year. This is a willingness-to-pay measure for a complete river clean-up.

Oster analyzed the survey results by cross-tabulating income with willingness-to-pay data and with increased use. She found that both increased with increased income.

Oster's study meets criteria E, F and G. Benefits are quantified in two ways, dollars and recreation activity days (E). The equity question is explicitly addressed in terms of differences in willingness-to-pay of different income groups (F). The method of benefit calculation is generalizable, although the data would have to be collected for each study area (G).

Critera A, B, C and D are not met. As explained above, a survey must be conducted each time the methodology is to be applied (A). Oster does not specify pollutants (B), she asks about payment to "clean up" the river. This is ambiguous. An alternative approach was used by Gramlich in his thesis on the Charles River (Harvard University, March 1975) who uses a more theoretical questioning technique, posing levels of clean water corresponding to standards for, for example, "swimmable" quality water. Although she investigates willingness-to-pay, Oster does not develop a functional relationship between willingness-to-pay and alternative water quality levels (C). Oster also does not specify a relationship between pollution, water quality and personal utility (D); she considers total utility for a total clean-up (undefined).

3. J. C. Day and J. R. Gilpin, "The Impact of Man-Made Lakes on Residential Property Values: A Case Study and Methodological Exploration," Water Resources Research, Vol. 10, No. 1, February 1974.

This study does not concern water quality impacts. However, it does explore certain methodologies that may be important for assessing the benefits of water pollution control. The analysis uses a market study method and a survey method to investigate the benefits of development of a reservoir on nearby property values.

Data are collected for 455 single family and apartment houses surrounding the project area. A regression analysis is performed to determine the factors associated with residential assessed property values (sales values would have been more meaningful, the authors contend, but only a small number of records were available). Distance from the reservoir predicted only 0.8 percent of the variation. Day and Gilpin feel that this result suggests that the reservoir project had not influenced assessed property values; so they tried an alternative approach, behavior analysis.

A survey was conducted of 35 percent of the dwelling units surrounding the project area to determine residents' perceptions of the value of the reservoir. Ninety-four percent did not know about the project when they moved to the area. The questionnaire requested interviewees to rank the factors which contributed to the benefit of living in the study area. Only two percent ranked the reservoir in their top four choices and these people lived adjacent to the project area. Seventy-one percent of those interviewed felt that the reservoir project did not affect property values. Day and Gilpin conclude that benefits are restricted to a small area contiguous to the lake property.

Since this study uses two methodologies, they will each be assessed in light of our criteria. The market study meets criteria A, C, E and G. The survey methods meets only F and G. The market study approach is appealing because it uses generally available data, land value assessments (A). The survey method, as in the Oster study, has to be repeated each time it is used. Regression analysis is a theoretically valid approach (C). The behavior analysis methodology is qualitative and therefore not theoretically valid. It could, however, be a helpful complement to a more rigorous method. The market study quantifies benefits (E). The survey does not, although benefits of the reservoir are compared to other benefits through ranking. The property value study does not address the equity question although it could be used to do so. The questionnaire, however, does show that certain benefits accrue only to those living adjacent to the water body (F). The property value methodology is generalizable (G). So are the survey and ranking analysis methodologies but they must be repeated each time.

Neither methodology meets criteria B or D since the study was not concerned with water quality, although they could be adapted to study water quality impacts. In particular, the behavior analysis methodology might be used to investigate the relationship between water quality and a value measurement.

4. Dow Chemical Company, An Economic Analysis of Erosion and Sediment Control Methods for Watersheds Undergoing Urbanization, Final Report, Midland, Michigan, February 1972.

This is one of the few analyses specifically concerned with sediment as a water quality determinant. The study relies on available cost data relating to sediment damages and presents average damage costs per ton of sediment entering the stream system. It is part of a larger report focusing on soil losses from urban construction sites which analyzes the cost and effectiveness of numerous sediment control systems. The economic impact of sediment in water was estimated for the Potomac River below the confluence with Seneca Creek.

The study assumes that a reduction of a unit of sediment provides a proportional reduction of cost, an assumption which probably holds for large scale sediment removal but does not apply to small reductions. From measurement of the existing total sediment transport in the river, a reduction in yearly average sediment load was estimated for the river to be considered "clear." This amount was used to reduce annual dollar damage estimates to dollars per ton of sediment removed.

Damages per ton of sediment to downstream water bodies are calculated in terms of uses which are defined as: metropolitan water supply; industry including electric power, dredging and commercial fishing; recreation including fishing and boating; aesthetics; and flood damage abatement benefits due to sediment control impoundments. Calculation methods are as follows:

Metropolitan Water Supply

The difference is calculated between chemical treatment costs, assuming the water is clear and existing treatment costs. Costs are linear versus sediment concentration so cost differences are divided by required reduction in sediment per year to give cost per ton of sediment removed.

Electric Power Improved cooling condenser design prevents plugging from fine particles so cost is not reduced by lower sediment concentrations.

Dredging From available data a cost per cubic yard for dredging is developed which includes disposal costs. This is multiplied by the past average amount dredged and divided by the required reduction in sediment per year.

Commercial Fishing The present dockside value of fish and shellfish is calculated. From data on the impact of suspended solids on trout and shellfish density as a percent of normal for "clean" streams, the increase of commercial catches is calculated assuming that it would increase proportionately to the fish population. The increase per ton of sediment is then determined.

Recreational Fishing An average number of fishing days is estimated from Fish and Wildlife Service forecasts and an average value per man-day for fishing is assumed. The average annual value of all fishing days in the area is calculated and the increase in value is calculated assuming the same fish density increases with reduction in sediment as for commercial fishing. Value returned per ton of sediment is determined.

Boating The number of pleasure boats using the tidal Potomac is estimated and annual total recreation expenses are calculated on the basis of amortization of an assumed average original cost and annual expenditures per boat. A percentage increase in boating due to clean water is assumed and a percent contribution to this amount due to sediment removal as well. The potential increase in value is calculated and divided by the annual tons of sediment required to be removed.

Aesthetics The number of visitors to the area is estimated and a proportion who are tourists is assumed. As a matter of national pride to help reduce sediment in the Potomac, an amount per visitor ($.25 - $.50) is assumed as reasonable value to ascribe to aesthetics. Based on this assumed value, the average amount of damage per ton of sediment removed is calculated.

Flood Relief Incidental to Sediment Control The annualized flood damages in the Potomac flood plain are estimated. The number of impoundments necessary for sediment control is determined and their flood prevention value in proportion to drainage area retained is calculated. This is divided by the annual amount of sediment trapped to yield a value per ton of sediment retained by impoundments.

The damages to the users of the Potomac River below Seneca Creek are summarized as follows in dollars per ton of sediment:

Metropolitan Water Supply	.31
Electric Power	0.00
Dredging	.67
Commercial Fishing	1.27
Recreational Fishing	.88
Boating	.84
Aesthetics	2.56
Subtotal	6.53
Flood Relief Incidental to Sediment Control	.27
TOTAL	6.80

The Dow Chemical Company study meets criteria A, B, E, F, and G. Existing data sources are used for calculating all damage estimates (A). A specific pollutant, sediment, is addressed (B). Benefits are quantified in dollars (E). The distributional aspects of sediment control are addressed in the identification of user groups who derive different amounts of benefit from sediment removal (F). The methodology is of a generalizable type which could be applied to other watersheds if comparable data were available (G).

Criteria C and D are not met. Despite the development of what appear to be functions relating tons of sediment removed to benefits, they are actually based on aggregate values and only assumed to be linear (C). Judgment values and assumed values and proportions are also used in several of the user benefit calculations. The value measurement for sediment removal is assumed to be equal to the dollar value of damages caused by the sediment (D). This is a valid concept. However, particularly for recreational fishing, boating and aesthetics, the dollar values chosen are not necessarily reflective of the benefits derived from the experience. Other problems with the analysis include the neglect of possible higher equipment costs for electric power plants and the cumulative impact of sediment on flooding.

5. Alan Randall, Berry C. Ives and Clyde Eastman, Benefits of Abating Aesthetic Environmental Damage, New Mexico University Agricultural Experiment Station Bulletin 618, Las Cruces, New Mexico, May 1974.

Randall et al evaluate the economic benefits to abating the aesthetic environmental damage associated with the electric power industry as perceived by users of the affected environment around the Four Corners Power Plant, Fruitland, New Mexico. The study uses the theoretical concept of aggregate bids or benefits for the provision of a public good as a basis for the analysis. Efficiency in the provision of a public good can be achieved by equating the marginal bid with the marginal cost.

The bidding game technique of data collection was adapted for use in this study. The purpose of the games is to pose hypothetical questions to measure the willingness of a sample of respondents to pay for environmental improvements. Five bidding games were developed to provide several benefit estimates. Respondents were shown three sets of photographs depicting three levels of environmental damage around the power plant. The highest level of environmental damage was chosen as the starting point and respondents were asked to respond yes or no to dollar amounts to elicit the highest amount they would be willing to pay to improve the environment to an intermediate level of damage or to minimal damage. The following types of games were used: regional sales tax (air quality region); additional charge to electricity bill to all who use the electricity produced by the plant even if they do not live in the region; monthly payment (no particular payment vehicle); addition to user fee for recreationists; compensation game which assumes that the respondent owns the environment and accepts monthly rent from the industry to damage the environment.

Determination of three points on the aggregate bid curve corresponding to the levels of environmental damage illustrated were calculated by aggregation methods appropriate to the stratified random sampling technique used. Marginal aggregate bid curves or price curves were generated by taking the first derivatives of the aggregate bid curves. Benefits of an intermediate level of aesthetic damage abatement were estimated at $11 to $15 million annually, while benefits of complete abatement were $19 to $25 million per year.

Calculation of the"income elasticity of bid" and the "electric bill elasticity of bid" indicated that bids for abatement were higher for households with higher incomes and for households consuming more electricity.

Questionnaire results suggested that financial arrangements for abatement of aesthetic environmental damage from the power plant should place the burden on industry and consumers of electricity.

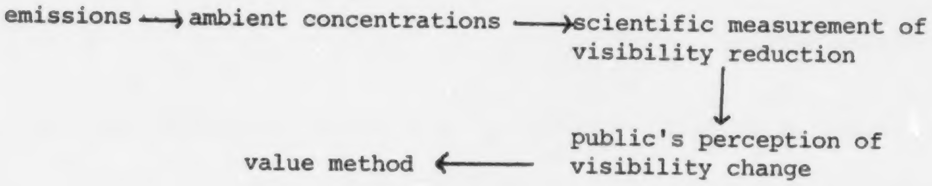
Criteria C, D, E, F and G are met by the Randall study. The object of the bidding games are to produce willingness-to-pay measures in response to changes in environmental damage (C). Water quality is not considered in this study but the relationship between aesthetic environmental quality and a value measurement is specifically addressed in the bidding games (D). Benefits are quantified in dollars (E). The distribution of benefits is considered through sampling different groups including recreationists and by investigating the elasticities of income and electric bill (F). Also, the method of using alternative games elicited information about the preferences for distribution of the financial burden for abatement of pollution from the power plant. The data collection and analysis methods were successfully used in this instance and could be applied elsewhere, however, a new survey would have to be taken (G).

The Randall study does not meet criteria A or B. To use the methodology tested in this study requires the development and execution of a reliable survey (A). A specific benefit, aesthetics, is addressed in this study, but the pollutants are many, including particulate emissions, power lines and strip mining (B).

6. Thomas D. Crocker, Robert L. Horst, Jr. and William Schulze, Multidisciplinary Research in Environmental Economics; Two Examples, paper prepared for the workshop on Multidisciplinary Research Related to the Atmospheric Sciences, National Center for Atmospheric Research, Boulder, Colorado, August 1977.

Crocker, Horst and Schulze discuss the valuation of atmospheric visibility to illustrate the application of an economic value measurement to a phenomenon generally considered to be intangible. The area chosen for study is the Four Corners regions around Farmington, New Mexico where the unique nature of the extended atmospheric visibility is valued as a public good.

The research approach chosen for the study was outlined as follows:


emissions
ambient concentrations
scientific measurement of visibility reduction
public's perception of visibility change
value method

No complete dispersion model was available to establish the first linkage between emissions and ambient concentrations. The second linkage was formed by taking pairs of black and white color photographs of identical scenes at the same time. The meteorological range represented by the black and white photographs was derived from a companion study. The third linkage was assumed to be one-to-one based on other research. A survey was used to make the fourth linkage.

A sample of the population of Farmington, New Mexico was surveyed and asked to choose which among three color photographs most accurately represented the ambient conditions during a week in the summer. The respondent was then questioned on how he spent his leisure time during that week including both activities and expenses related to those activities. He was then asked regarding thee chosen activities, how he would change his use of leisure time if conditions were as they appeared in the other two photographs.

The authors used the household production theory (product substitution and unit prices per hour) approach to develop compensated demand functions for visibility from the survey data on time budgets and expenditures. Compensating income surplus for a reduction in visibility was calculated to be about forty dollars a week (in 1976 dollars). This is a measure of what the individual would have to be paid to tolerate reduced visibility.

The Crocker study meets criteria C, D, E and G. A demand function for visibility is generated using the economic model developed in the study (C). Although the study concerns air quality rather than water quality, the relationship between personal utility and pollution levels is specified in the research approach and the economic model (D). Benefits are quantified in dollars (E). The study demonstrates that an analytically sound implementable model can be constructed to value aesthetic phenomena (G). However, the data necessary to implement the model must be acquired empirically.

Criteria A, B, and F are not met. As just mentionned, the data on which this method is based must be collected for each case to which the model is applied (A). The research outline for the study indicates that the relationship between emissions (specific pollutants) and ambient concentrations was not specified because of the lack of a complete model (B). If this type of model were available for use with the economic model, then this criteria would be satisfied. The study does not address the question of distributional impacts (F).

7. S. D. Reiling, K. C. Gibbs and H. H. Stoevener, Economic Benefits from An Improvement in Water Quality, prepared for the Office of Research and Monitoring, U.S. Environmental Protection Agency, Washington, D.C., January 1973.

Reiling, Gibbs and Stoevener test a methodology for estimating the economic benefits accruing to society as a result of water quality improvements and associated recreation increase at Klamath Lake, Oregon. Benefits to the local economy are also estimated.

The demand model is based on two prices which determine the number of visitor-days which recreationists consume, the cost of travel to the site which does not vary with the length of stay and the on-site cost. The methodology designates a critical level of these costs beyond which the recreationist will choose not to recreate at the site at all. Cost variables are expressed on an individual basis rather than for the recreation group. Travel costs include transportation, food expenditures, lodging, camping fees and other expenses. On-site costs include lodging, camping fees, equipment rentals, meals and miscellaneous expenses. Other variables for the model are demographic characteristics of the recreationist, income after taxes and site characteristics which include the size of the lake and use-intensities for water-related activities. These last are subjective variables reflecting low, medium and high use for fishing, boating, etc. It is assumed that the level of these activities is dependent on the water quality and other physical features of the lakes. It is noted that it would be more satisfactory to specify the model with respect to the biological and physical parameters of the lake directly; but these data were not available.

Survey data collected at Klamath lake and at three other nearby lakes with varied characteristics are used to estimate equations of the statistical demand model. Four relationships are estimated: the critical on-site cost, the critical travel cost, the demand relationship and the number of visits relationship. The recreational value of each lake was determined from the demand model by calculating the consumer surplus which is a function of on-site costs, length of stay per visit, travel costs and average income. The resulting per visit value was multiplied by the estimated number of visits to give a net economic value for Klamath Lake for 1968 of $82,000. The relationship derived between the number of visits to a site and the characteristics of the site was used as a predictor for percent increase in visits to Klamath Lake if water quality improved. New use-intensity ratings were hypothesized for the lake given a hypothesized two-stage improvement in water quality. The increase in visits based on the new use-intensity ratings was calculated, and based on this increase, the new economic value was estimated. The first stage of water quality improvement, removal of algae, would yield $1.2 million worth of recreation benefits and the second stage, lower water temperature and beach improvement, would yield an addition $2.66 million.

The impact of expanded recreational use of Klamath lake upon the local economy is estimated through the use of an input-output model of the Klamath County economy. The model measures the gross flow of goods and services between sectors. A sampling of the sectors of the economy were surveyed to obtain the necessary detailed financial data for construction of the transactions matrix. Data from the demand model were used to obtain total expenditures in Klamath County associated with recreation by sector. The recreation expenditures are viewed as part of final demand of the input-output model affecting total output and household income. Regional recreation benefits for 1968 for Klamath Lake are calculated from the input-output model to be $227,000 of household income. The hypothesized two-staged improvement in water quality discussed above would increase household income by $347,820.

The Reiling, Gibbs, Stoevener study meets criteria C, E, F and G. They develop a demand function which is used to estimate the recreational value of each lake studied (C). The input-output model is also based on sound economic principles. Benefits are quantified in dollars and secondary benefits to the local economy are also estimated (E). The distributional aspects of the impact of water quality improvements are addressed by the use of the input-output model which indicates which sectors of the economy benefit from increased recreation expenditures (F). The methodologies used in the study are applicable elsewhere, although both the recreation survey used to provide data for the demand model and the survey of the regional economy for the input-output model would have to be carried out at each location studied (G). There would also have to be agreement on the values assigned to the use-intensity variables for the methodologies to be used in any comparative manner.

Criteria A, B and D are not met by the Reiling study. To implement either of the methodologies used would require a survey data collection effort although other study areas might have more readily available financial data for an input-output model (A). Water quality parameters are not specified in the model (B). As mentioned earlier, the authors feel that a more satisfactory model would relate changes in the physical characteristics of the water resource to responses in human behavior but that these data were not available (D).

8. Battelle Memorial Institute, "The Impact of Mine Drainage Pollution on Industrial Water Users in Appalachia," Appendix A to Acid Mine Drainage in Appalachia, a report by the Appalachian Regional Commission, Columbus, Ohio, March 1969.

The Battelle Memorial Institute conducted a study to estimate the effect of mine drainage pollution on the cost of water use by industry in Appalachia. The impact on regional industrial activity was also examined.

The study focused on the effect of mine drainage on production techniques and production costs. The necessary data could only be obtained by visits to industrial plants and by detailed interviews with plant and company personnel. Sixty-seven in-plant interviews were conducted in six river basins. The sample of plants to be interviewed was chosen to pinpoint those industrial water users most likely to be affected by acid mine drainage. This involved collection of data on the general water use characteristics and water quality sensitivities of all major Appalachian industrial water users. Other data collected included: the costs of water utilization for water supplies, pumping, treatment, distribution, recirculation and waste treatment; the proportion of water costs to the overall value of industrial production; methods adopted by industries to adjust to mine drainage conditions; and costs of adjustments to mine drainage.

The economic impact of acid-mine drainage was inferred from the interview data. Detailed cost estimates were developed for various methods of treating mine drainage polluted industrial water supplies, including treatment at the source and lime neutralization. A hypothetical three-stage reduction in mine-drainage pollution was assumed and treatment costs were applied to interview data to obtain estimated savings. The following costs and potential savings were investigated: costs of alternative water sources (savings from substituting raw surface water); costs of using modified equipment; abnormal operation, maintenance and replacement costs of production equipment or water-system components; costs of product adjustment (savings in product quality control); costs of treating mine-drainage derived contaminants in withdrawal of direct supplies of water from mine-drainage rivers; costs of treating mine-drainage derived contaminants in water purchased from municipal or other supplies affected by acid-mine drainage. Expected changes in production were also analyzed, including new levels of output, new location, new products, new quality of output given reduced production costs resulting from reduction in mine drainage. The results for the sample were then projected to include the entire manufacturing sector within each river basin surveyed.

The survey showed the maximum savings from pollution reduction would occur from treatment at the source rather than lime neutralization. The maximum possible savings from a 90 percent reduction in mine drainage at the source in all Appalachian river basins is $1,230,000. The greatest portion of the savings come from savings in chemicals used in conventional methods of water treatment. The major savings would be to large plants directly using river water. Fifty percent of the entire savings would accrue to several very large steel producing plants in one region of Pennsylvania. It was found that adjustments to acid-mine drainage accounted for only a small fraction of total water costs at manufacturing plants which themselves were generally less than one percent of the total value of sales. The study concluded that no regional industrial impacts including water use, production, employment and use of raw materials and power would occur as a result of reduction in acid-mine drainage.

The Battelle study meets criteria B, C, D, E, F, and G. A specific pollutant, acid-mine drainage, is the focus of this study (B). From the survey data, functional relationships are developed showing the savings resulting from various levels of pollution reduction depending on the type of treatment employed (C). The detailed industry-by-industry investigative work done for this study was aimed at identifying the economic impact of a specific pollutant on a specific receptor, the manufacturing industry in Appalachia (D). Benefits of pollution reduction are quantified in dollars (E). Distribution of the savings from mine drainage reduction was considered for different industry groups and between large and small industries (F). The methodology employed in this study can be applied to other regions, and in many cases, is the only way to understand the financial impact on industry of environmental improvements (G). It, of course, involves expensive detailed interviewing.

As just mentioned, because of the techniques necessary for data collection for this type of study, application is not easy and therefore it does not meet criteria A.

Summary of Reviews

This assessment of benefit studies has shown that few studies meet all criteria. Criterion A, ease of application, proved to be the most difficult criteria to satisfy. This is primarily because response to changes in environmental quality is such a complex subject and there are few relevant studies. Three of the studies summarized here do meet criteria A: the Tihansky study, and the Dow Chemical Company study, and the property value study by Day and Gilpin. In the Tihansky study, the benefit group chosen, household water supply, and the pollutant, dissolved minerals, had generated enough research interest so that there were data available on which to develop a damage function relating pollutant to economic value. The Dow Chemical study used data (where available) and judgment values where sufficient data were lacking.

Of the methods in the three Studies satisfying Criterion A, the property value technique employed by Day and Gilpin is most appealing because it relies on existing (secondary) data, either property tax assessments or sales prices and census data. However, there are shortcomings to the approach, including the difficulties involved in selecting a site for cross-sectional or time series study, where the effects of changes in water quality can be isolated. (For example, see discussion on pages 6 to 9 in Darroger and Dornbusch, 1973.) problem with the property value approach is discussed by Binkley and Hanemann. They note that if property values rise near a water body they may fall in an area further away from the water body and simply knowing how much property values change near the water body will not allow conclusions regarding change in social welfare. (See S. Binkley, W. Hanemann, Urban Systems Research and Engineering, Inc., pages 14-18.)

The failure of several studies to meet criterion D, *pollution level-value measurement relationship*, points to a major problem in benefit estimation. The lack of existing data that link pollutant and value measurement results in the need to conduct surveys or undertake other expensive data collection efforts. A study that requires primary data collection to establish this relationship therefore does not meet criteria A. Such empirical data for many water quality parameters, and especially for interactions among water quality determinants, is not readily available. Studies which do meet criteria D are the Tihansky, Battelle Institute, Randall and Crocker studies. Both the Tihansky and Battelle Institute studies are concerned with pollutants which affect the cost of production, the former for the household and the latter for industry and both are able to specify defensive expenditures for different levels of pollution. The Randall and Crocker studies specifically establish the connection between pollution levels and value measurement in their surveys.

Criteria B, consideration of identified pollutants, is a third area of difficulty with most of the studies considered. Only the Tihansky, Dow Chemical Company, and Battelle Institute efforts address specific pollutants (dissolved minerals, sediment and acid-mine drainage, respectively). Other studies focus on more general types of pollution such as lowered visibility, or rivers and lakes with poor water quality, and do not develop data or methodologies to handle individual pollutants or combinations of pollutants.

Criteria C, E, F and G (theoretical validity; benefit quantification; distribution of impacts; and generalizability) are more readily met than A, B or D. The Tihansky, Day and Gilpin, Randall, Reiling and Battelle Institute studies satisfy these criteria. These studies are based on accepted methodologies, and they quantify benefits in dollar terms. They address the equity question in different ways, including comparing impacts on different regions, different income groups, different industries or sectors of the economy, or different population groups defined by location or consumption. The techniques employed in these studies are reproducible in other locations for other problems, however, most would require new data collection efforts. The Crocker study meets criteria C, E and G but does not address the equity question. The Dow Chemical Company and Oster studies satisfy criteria E, F and G but calculate aggregate benefits rather than developing a functional relationship between benefits and levels of pollution.

From review of benefit methodologies presented here it appears that there are several approaches for evaluating water quality impacts from agriculture that could be developed for empirical testing. Table E-2 shows which methodologies are most appropriate for particular activities, uses or groups. Referring back to the studies reviewed, examples of methodologies applied to specific benefit categories include:

1) time budget - Crocker study of aesthetics;
2) bidding games - Randall study of aesthetics and Oster study of recreation (a less sophisticated example where aggregate willingness-to-pay data is collected);
3) travel cost - Reiling study of recreation;
4) marginal cost - Tihansky study of household water supply and Battelle Institute study of industrial water supply;
5) net factor income - Dow Chemical Company study of commercial fishing (among other things);
6) market study - Day and Gilpin study of property values;
7) non-dollar measurement - Day and Gilpin's value ranking study and;
8) input/output model - Reiling model to estimate local economic benefits.

Table E-2. Comparison of Methodologies to Measure Water Quality Benefits

Methodology Types	Benefit Categories										
	aesthetics	recreation	property values	human health	commercial fishing	agriculture	municipal water supply	industrial water supply	dredging (navigational, flood control)	ecology	local or regional economy
time budget	X	X									
bidding games	X	X		X							
travel costs		X									
marginal costs				medical costs & lost earnings			treatment production costs	treatment production costs	X		
net factor income					yield change x price	yield change x price					
market study			X								
non-dollar measurement	ranking	ranking								change in habitat	
input/output model											X
alternative cost										cost to reproduce	

We have not reviewed a study devoted to valuing water quality benefits to ecology (alternative cost); (for a good discussion of the sparseness of the literature in this area, see Jordening, L., Development Planning and Research Associates, Inc., pages 47-48).

As indicated in the above discussion, there are trade-offs involved in choosing a methodology appropriate for use in estimating benefits to water quality groups. The major one is the use of readily available secondary data versus the need for a theoretically valid model which relates specific pollutants to a value measurement. An example of this tradeoff is the Dow Chemical Company study which resorts to judgment and aggregate values, due to the lack of required data. There are more data available for certain benefit categories such as household water supply than for others such as aesthetics (see earlier discussion of Tihansky study). Surveys are expensive and time consuming but there does not appear to be any feasible alternative especially for measuring recreation or aesthetic benefits which are two of the major categories in which benefits from reducing nonpoint source pollution lie.

Another related problem is the need to isolate specific pollutants and to relate them to a value measurement. Photographs are used in the two studies concerned with air pollution (Crocker and Randall), a sediment load standard is developed in the Dow Chemical Company report, and dissolved mineral concentration levels are specified in the Tihansky study. These are examples of mechanisms employed to match a physical measure of environmental quality to a measure of value to people. In cases where more than one water quality parameter is of interest, as is often the case for water quality problems, the problem is much more difficult. Again there is a trade-off between choosing a methodology which develops a valid functional relationship and one which examines benefits in the aggregate.

Several of the methodologies which we have reviewed can be used to investigate the distributional aspects of water quality benefits. For instance, bidding games can be applied to different population groups defined by location or income, methods to evaluate the marginal cost of treatment or production can be used to examine differences in benefits among industry or household groups or among geographic regions, and the input-output model may be used to focus on impacts to alternative economic sectors. The major concern here, of course, is the definition of equity, the decision to choose certain groups whose welfare is of enough importance to require the focus of the study. As we have seen, many groups are important depending on the region or problem of concern.

The land/water configuration and land uses of the study area become important factors in determining the appropriate methodology(ies). Is the water body a large flood control impoundment that is widely used for recreation or is it a river used for municipal water supply and industrial cooling water? Is it a small stream running through agricultural land used by local sport fishermen or is it an estuary used as a commercial fishery and for navigation purposes. These kinds of questions must be answered to determine which impact groups are likely to derive the most benefit from improvements in water quality. Choice of impact groups will in turn reduce the number of candidates for benefit methodology. If a number of beneficiary categories appear to be important then several different instruments may have to be employed simultaneously. This, of course, will increase the scope and expense of a benefit study.

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Appendix F

Crop Response to Fertilizer

One of the policies evaluated in Section 6 of the report pertains to mandatory reduction in the use of fertilizer as a way to improve water quality. This analysis provides the basis for estimating yield reductions and farm revenue changes that are treated in Section 6.

To estimate the effects of fertilizer usage on farm revenues (as well as water quality) it is necessary to relate application levels to yields. Nitrogen and P_2O_5 are the fertilizers of primary interest.* The work of Taylor and Frohberg (1) for Illinois appeared attractive because optimum levels of nitrogen application are related to yield (expressed as a percent of maximum yields attainable) for a range of corn to nitrogen price ratios. Moreover, small differentials in yield are estimated in the range where optimal results are anticipated,** i.e., where marginal costs and marginal returns are equal. (Some other data, developed expressly for Indiana available at the outset of work, were considered inadequate because average statewide conditions are treated, rather than specific counties or soil types relevant to the Black Creek area (e.g., (4) and (5)). If the Illinois yield-nitrogen response relationships could be made applicable to Indiana, we would be able to investigate conditions where relatively large reductions in nitrogen (e.g., 14 percent) applications result in small reductions in yield (e.g., one percent).

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* The K_2O fertilizer is not analyzed because crop response and water quality are less sensitive to potassium than to nitrogen and phosphorus.

** For example, Taylor and Frohberg list seven nitrogen application rates which cover a range of corn yields from 100 percent of maximum yield to 99.1 percent.

Data on corn response to nitrogen for Indiana were then obtained from Meta's field work (2, 3). Tests had been carried out for a range of nitrogen applications from 0 to 180 pounds per acre on Blount Silt Loam and 0 to 210 pounds per acre on Odell Silt Loam on the two different soil types identified as relevant to Allen County (2, 3). However, the test results are of limited value because only two intermediate levels between zero and maximum nitrogen application are reported. A comparison of Indiana data with Taylor/Frohberg (1) was made to see if the relationship developed for Illinois could be applied to the Indiana Odell Silt Loam soil and thus establish a more precise estimate of yield response to nitrogen in the range of near maximum yielded conditions, i.e., where only small yield reductions occur with sizeable reductions in nitrogen application. Fig. F-1 shows the comparison between Illinois crop response (1) and that for Indiana on one type of soil (3). The four data points provided by the Indiana tests (shown for three different applications of P_2O_5) indicate a fundamental difference in the Indiana crop response compared to Illinois. At low rates of nitrogen application (0 to 1.0 pounds nitrogen per bushel of yield), yield improvements are greater on the Indiana soils than on the Illinois soils. Also it is seen that maximum yield in Illinois occurs with 1.34 pounds nitrogen per bushel

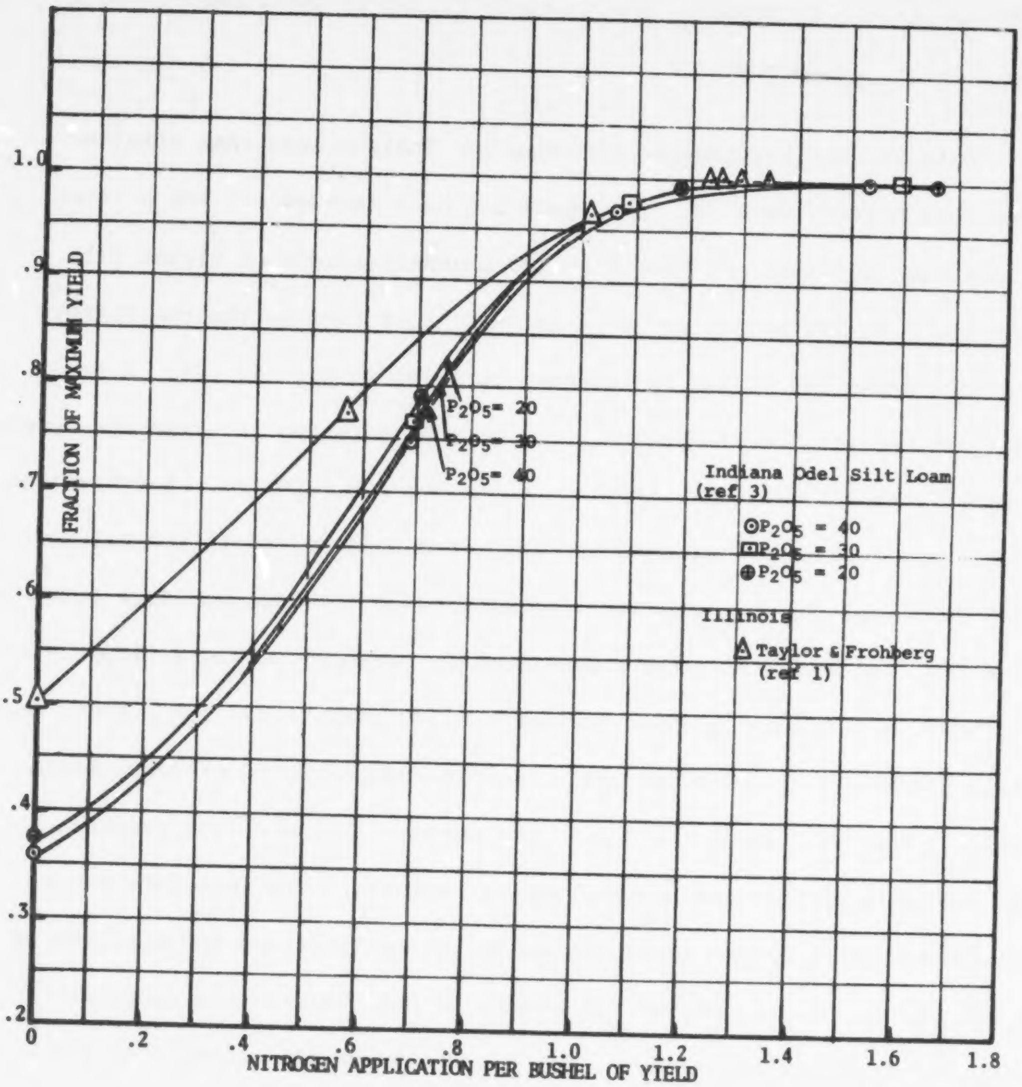

Figure F-1. Comparison of Indiana Tests (1967-69) to Illinois (Taylor-Frohberg) in Corn-Nitrogen Response yield while maximum yields in Indiana occur at application rates between 1.43 and 1.67 depending on the level of P_2O_5 application.* Thus, for maximum yield in Indiana on Odell Silt Loam soil of 130 bu/acre, the Illinois response function would estimate a nitrogen application rate of 174 lbs/acre (1.34 lbs x 130) whereas Indiana tests indicate 185.9 to 217.0 lbs/acre are needed.

The yield response data from Reference (1) were therefore judged unsuitable for Indiana Odell Silt Loam. However, the Illinois response function was utilized in the subsequent steps for Odell Silt Loam as an aid in approximating the general shape of the Indiana response function because only four nitrogen application rates are reported from the Indiana Tests. For the Blount Loam soil, the Illinois response function was ignored; the yield response to nitrogen on Blount Loam soil is even more divergent from the Illinois function than the Odell Silt Loam soil.

For the Odell Silt Loam (used for soil types 4 in Black Creek), corn response for applications of 0, 70, 140 and 210 pounds of nitrogen are reported for four different rates of P (i.e., 0, 17.6, 35.2, 52.8 lbs per acrs). Average yield over the period 1967 to 1969 is plotted as a function of P for the four nitrogen application levels as shown in Fig. F-2. A cross plot of yield versus nitrogen application was then made for three specific rates of P_2O_5 as shown in Fig. F-3.** Fig. F-3

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* In Reference (1) phosphorous and potassium application rates are assumed to be equal to the amounts removed in the grain which should approximately maintain the P and K levels in the soil and thus the yield response is essentially dependent only on the amount of nitrogen applied.

** Where P = .44 (P_2O_5).

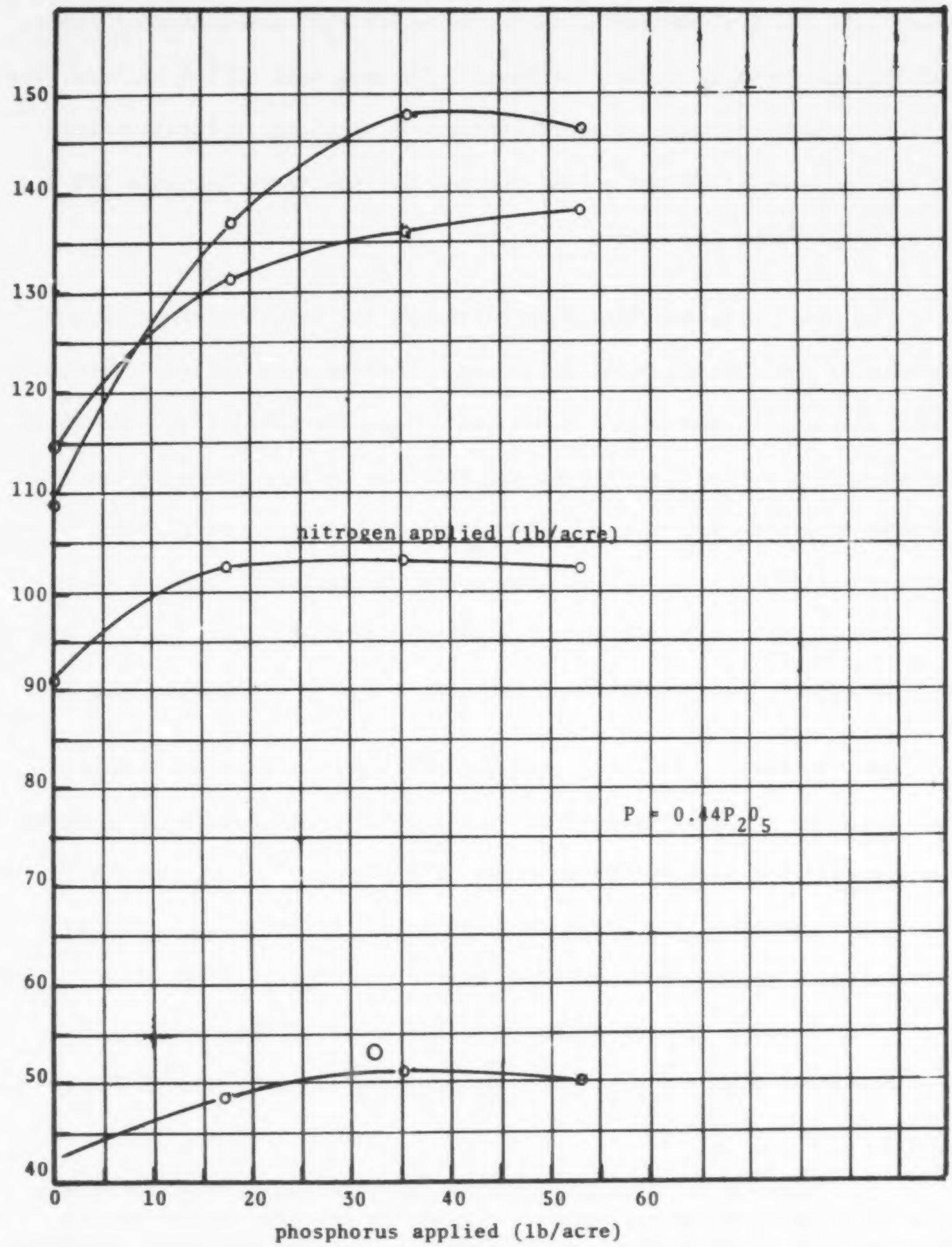

Figure F-2. Yield Response of Corn to Fertilizers (Odell Silt Loam)

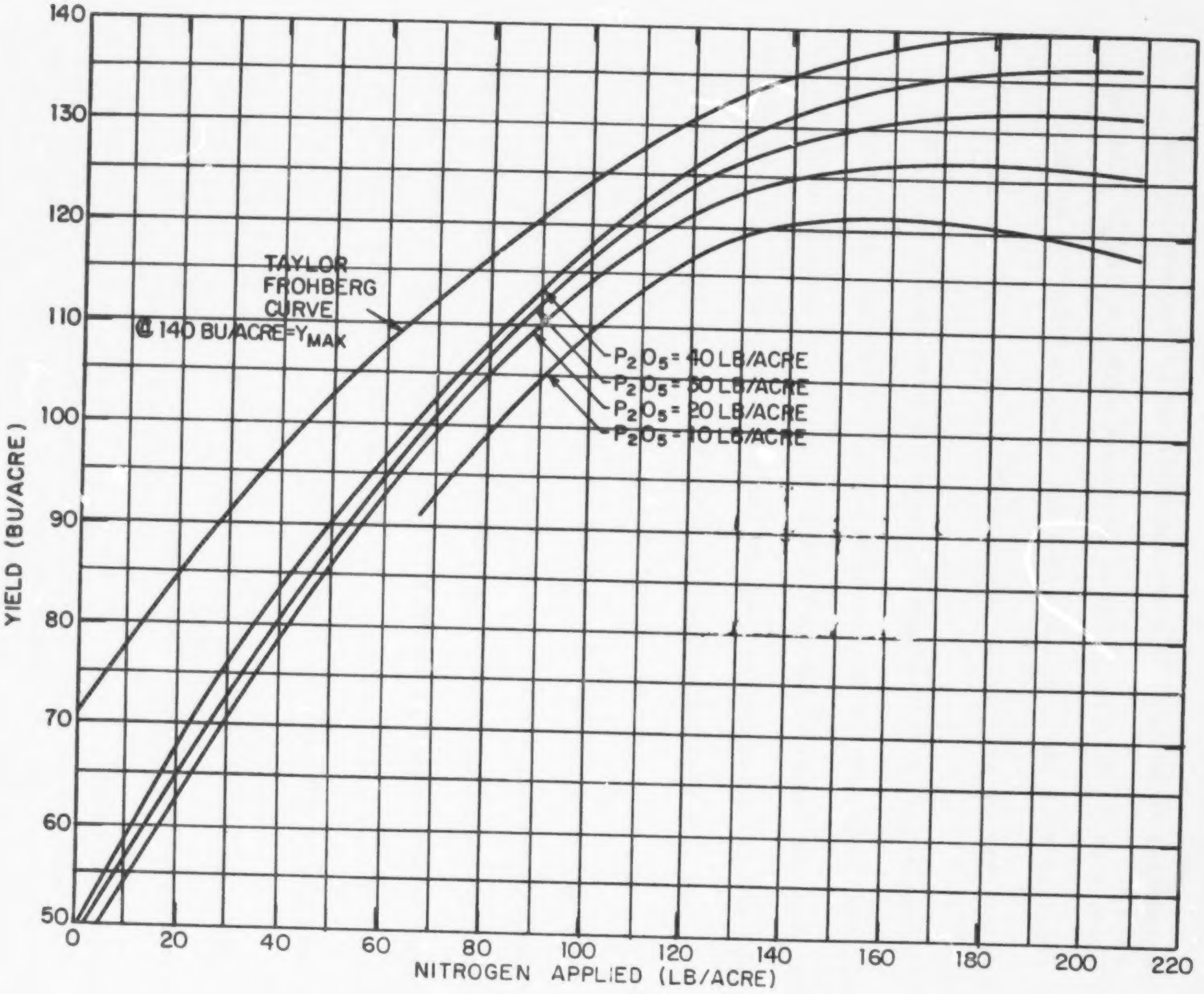

Figure F-3. Yield Response of Corn to Fertilizers (Odell Silt Loam) includes the Taylor/Frohberg response function which served as a guide for interpolating between the four data points reported in the Indiana tests. Nitrogen application of 160 lbs/acre and P_2O_5 of 30 lbs/acre were recommended to achieve an expected yield of 130 bu/acre in the Black Creek area.* This is in close agreement with the yields (131 bu/acre) obtained from the P_2O_5 crossplot and shown in Fig. F-3 at an application rate of 160 lb/acre of nitrogen.

For the Blount Silt Loam (used for soil types 1 and 3 in Black Creek), corn response for applications of 0, 40, 80, and 120 pounds of nitrogen are reported for 1962 and 1963 while applications of 0, 60, 120, and 180 are reported for each of the next two years. Average yields for 1964 and 1965 were calculated as a function of nitrogen application. These data are reported to a constant P_2O_5 of 120 lbs/acre. (The 1962 and 1963 data were eventually excluded in our analysis because it is questionable whether maximum yields were attained with an upper limit of 120 lbs/acre of nitrogen. The 1964-65 average indicates that maximum response occurs somewhere between 120 and 180 pounds of nitrogen per acre. Therefore actual yield was expressed as a percent of yield achieved with 120 lbs/acre of nitrogen as shown in Fig. F-4.

The next step was to adjust Fig. F-4 for two different yield-nitrogen levels recommended for use in our project by H. Galloway. For lowlands

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* Recommended by Harry Galloway, Purdue University. Based on later information the P_2O_5 was increased to 40 lbs/acre, with no change in the 130 bu/acre yield. Fig. F-3 was not reconstructed to depict the later information. However the response curve, used to estimate yield reductions with reduced nitrogen application for the Section 4 policy analysis, is based on the shape of the 40 lb/acre P_2O_5 curve shown in Fig. F-3.

(soil type 3) the recommended N is 160 lbs/acre and 30 lbs/acre of P_2O_5 with yields in the Black Creek area expected to be 130 bu/acre. For uplands (soil type 1) the recommended N is 140 lbs/acre and 30 lbs/acre of P_2O_5 for an expected yield of 120 bu/acre. From Fig. F-4 it is seen that with N = 160 for lowland soils, the yield is the same as at N = 120, the yield at other levels of nitrogen application is obtained by multiplying the response function value (i.e., percent of yield at 120 lbs/acre nitrogen) by 130 bu/acre.

For upland soils at N = 140, Fig. F-4 shows that expected yield is 1.022 times the yield at N = 120. Since we force the relationship of 120 bu/acre yield at N = 140 to comply with Galloway's estimate, the reference yield (at 120 lbs/acre of nitrogen) must be reduced to 117.4 bu/acre (i.e., 120 bu/acre ÷ 1.022).

All the above calculations for soil types 1 and 3 are based thus far on the yield-nitrogen response data which are reported to a fixed level of P_2O_5 of 120 lbs/acre. We next must adjust the derived yield-nitrogen reponse for the much lower, recommended, level of $P_2O_5$of 30 lbs/acre for Black Creek. Four different P_2O_5 levels (0, 30, 80, 120 lbs/acre) are reported (3) with nitrogen at a constant 180 lbs/acre. These data indicate the same maximum yields were obtained at P_2O_5 of 80 lbs/acre as with P_2O_5 of 120 lbs/acre. Furthermore, maximum yields were reduced by only one percent and 3.7 percent for P_2O_5 of 30 and zero respectively. Based on these reductions, the yield response for P_2O_5 = 120 (depicted in Fig. F-4) was adjusted by factors of 0.99 and 0.98

to obtain the yield-nitrogen response curves for P_2O_5 = 30 and 20 respectively. The final response curves shown in Fig. F-5 for soil types 1 and 3 have, therefore, been derived from Fig. F-4 but with adjustments to incorporate applications of P_2O_5 and nitrogen to give the expected yields recommended to Meta Systems (by Galloway) for soil types 1 and 3.

To investigate the sensitivity of water quality to various fertilization levels based on the yield response relationships, changes in nitrogen and P_2O_5 application were postulated and applied to the derived yield response functions. Decreases in nitrogen levels of 13 percent from rates recommended by Galloway would be desirable according to Commoner (6) to reduce nitrate concentrations for surface water for the East Central region

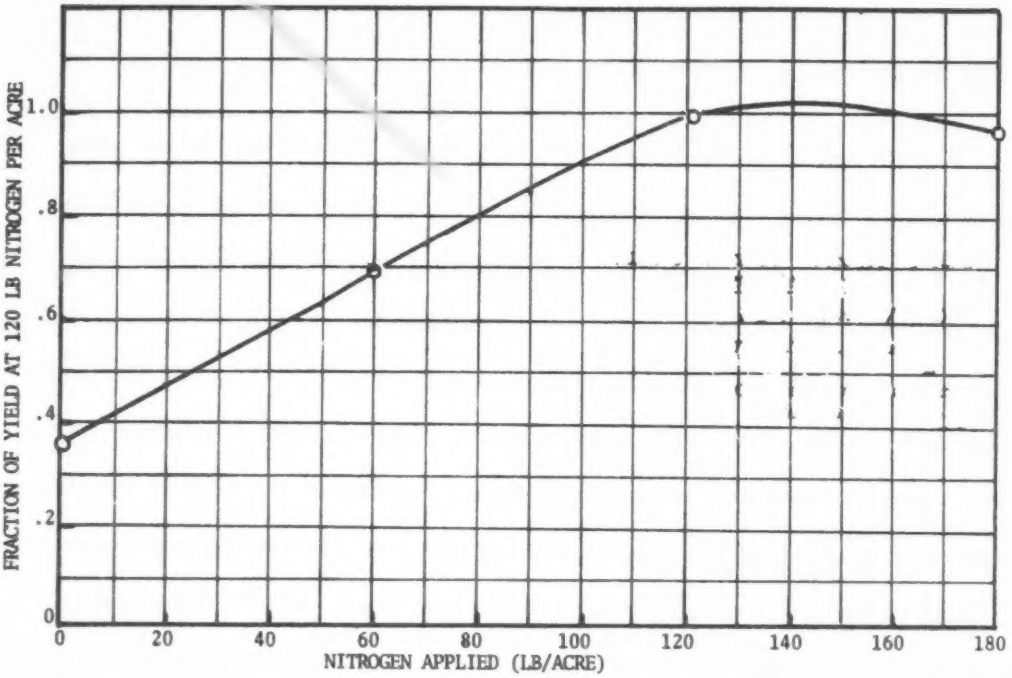

Figure F-4. Yield Response of Corn to Nitrogen (P_2O_5 = 120 lb/acre) Blount Silt Loam. o = Data Points from Ref. 3.

of Illinois. Commoner indicates that if the rate of fertilizer application were reduced to 146 kg of N per hectare corn (from a level of 168 kg of N per hectare), the 10 ppm standard would be exceeded no more than five percent of the time during the spring months.

In addition, two cases were postulated to evaluate the impacts on yield from changes per acre reduction in nitrogen which is a lesser reduction than dictated in P_2O_5 application to corn. The changes in the recommended P_2O_5 level were stipulated on an arbitrary basis. The recommended levels of P_2O_5 were increased and decreased in 10 pound increments. In preliminary studies, these changes in phosphorus fertilization rates were found to have negligible impacts on water quality and therefore were not considered further.

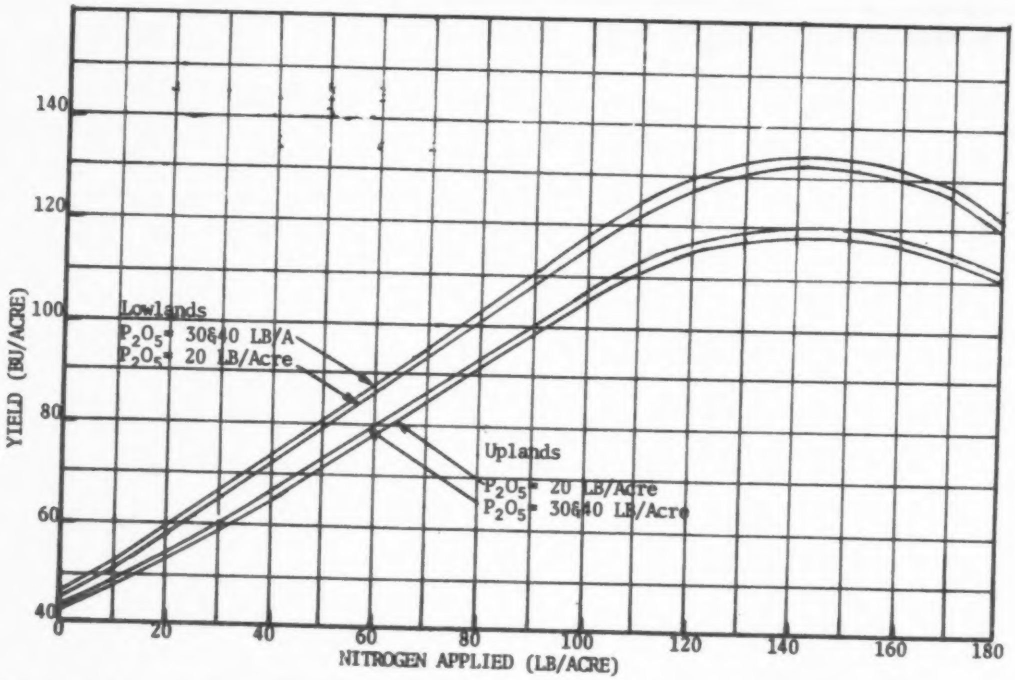

Figure F-5. Yield Response to Nitrogen (Blount Silt Loam)

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